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Safeguards & Security Review

Nondestructive Analysis of Special Nuclear Materials

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Safeguards & Security Review

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Nondestructive Analysis of Special Nuclear Materials: Current Research Projects

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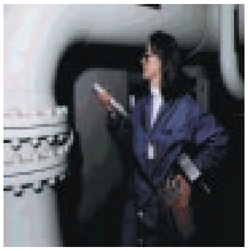
The identification and quantification of special nuclear materials (SNM)—plutonium and uranium—are essential components of many of the nation's domestic and international activities related to nuclear technology. These include safe storage and handling, shipping and receiving, weapons dismantlement, nonproliferation, waste management, and nuclear smuggling. Materials protection, control, and accountability require analyses of a wide variety of samples to characterize their SNM content.

Nondestructive analysis (NDA) assays the SNM content of a sample in a manner that does not disturb the sample. Generally, not even the package containing the sample is opened. For the most part, NDA relies on the detection of neutrons, gamma rays, x rays, or heat resulting from the nuclear decay of the SNM to identify or qualitatively and quantitatively analyze the material.

Various NDA techniques take advantage of one or more of the types of emissions from SNM. These techniques are often used in combination. For example, gamma-ray spectrometry identifies the SNM species present and determines the percentage of each, while calorimetry determines the absolute amount of material present from the heat generated by the sample. NDA techniques can be passive, that is simply detecting the emissions as given off. They can be active, that is stimulating the sample to emit additional detectable radiation. The irradiation of SNM by neutrons followed by detection of the additional gamma rays emitted is an example of an active technique.

This report reviews the current research and development of many NDA analyses and techniques. The goals of these R&D projects include advancing the state-of-the-art of NDA methods in general, applying known technology to new SNM measurement scenarios, increasing the accuracy and reliability of methods and systems, and making systems and methods more user-friendly.

Articles are arranged in four somewhat arbitrary sections: gamma-ray spectrometry, neutron assay, x-ray and calorimetry techniques, and applications of these methods. The application of new knowledge and technology, as described in these articles, will continue to advance our ability to identify and quantify plutonium and uranium to meet our national needs. These measurements are not only important to materials protection, control, and accountability, but they also support other programs, such as criticality safety, employee health and safety, and nuclear nonproliferation.



A Field Gamma-Ray Spectrometer Using Xenon at High Pressure

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Figure 1. The assembled Mark II spectrometer has attached to the top flange a vacuum/high pressure valve, a pressure transducer and relief device, and 20-kilovolt vacuum feedthroughs, providing the necessary electrical potentials to the internal electrodes. The chamber is fabricated from a light, high-strength titanium-vanadium-aluminum alloy (Ti_6Al_4V) that combines a high strength:weight ratio with good transmission for gamma rays.

Practically all nuclear materials of importance in nuclear safeguards, arms control, and nonproliferation regimes emit gamma rays, constituting a characteristic signature for these materials, and can be used to detect their presence and determine their properties. Two general categories of spectrometers are available to to measure these spectra:

1. Semiconductor detectors, usually high-purity germanium, have excellent energy resolution (typically better than 2 keV at an energy of 1 MeV), but they must be maintained at low temperatures with liquid nitrogen or mechanical cooling systems.

2. Scintillation detectors, usually sodium iodide (NaI), have the advantage of portability, but they have poor energy resolution (for example, typically 10%, or 40 keV at an energy of 400 keV).

New and expanded requirements for gamma-ray measurements of nuclear materials require detectors that can be widely deployed and function independently for prolonged periods of time and in a wide range of environments, with an energy resolution considerably superior to that of a scintillation spectrometer.

Brookhaven National Laboratory has developed a portable gamma-ray detector with high energy resolution. The detector is an ionization chamber that uses xenon gas at very high pressure (60 atm). Detectors of this type have only been used by the physics research community.

In our device, the energy of a gamma ray that has been stopped in the xenon is determined by collecting and measuring the number of electrons liberated in the gas by this ionizing event. Because of the high density of the xenon, its high atomic number, and its superior energy resolution, the ionization chamber's sensitivity for detecting individual gamma rays is in the same range as a NaI scintillation spectrometer. Unlike the scintillation spectrometer, the ionization chamber requires very little power, and it possesses a fairly wide operating envelope (temperature, pressure, acceleration, etc.), making it suitable for prolonged, unattended operation in a wide range of environments.

The Mark II spectrometer, filled with xenon, weighs approximately 10 kilograms (Fig. 1). A typical example of the Mark II's performance is shown in Fig. 2, where the spectrum of a ^{133}Ba source is compared with a spectrum of the same source obtained with a NaI scintillation spectrometer. The energy resolution obtained for the 356 keV peak is 15 keV, a three-fold advantage over the scintillation spectrometer. Modest further improvements in the energy resolution are possible using ultra-low noise preamplifiers also developed at Brookhaven.

Under the DOE-sponsored MIMS (Modular Integrated Monitoring System) program—whose purpose is developing unattended ground sensors—Sandia National Laboratories developed a communication network based on Lonworks technology, including a data-logging computer and a Sandia-developed interface. We integrated the Mark II into the MIMS network. The information transmitted to the MIMS network consists of a ten-channel packet that contains normalized peak areas of the principal gamma rays of plutonium, americium, and uranium. Data of this type have been acquired with the spectrometer, processed, and transmitted to Sandia.

The Mark II spectrometer is currently being incorporated into a package that includes the spectrometer, preamplifier, power supplies, etc., providing a dry, hermetic enclosure for the high-voltage circuitry. Combined with a portable multi-channel analyzer and a laptop computer, the complete system weighes less than 20 kilograms. To satisfy regulations concerning the shipment of pressure vessels, the system will be transported in a second, larger "overpack" designed to contain the xenon gas at a pressure of 200 psi if gas is vented for any reason from the spectrometer chamber. This approach will permit the shipment of the spectrometer by any means, including passenger aircraft.

The spectrometer possesses a number of features that speak for its utility in a number of DOE applications:

- Operation at ambient temperatures and in a wide range of environments hostile to other types of radiation detectors.
- Superior energy resolution
- Low power consumption.
- The ability to function simultaneously both as a gamma-ray spectrometer and a slow neutron detector with the addition of approximately an atmosphere of He^3.
- The ability to operate over long periods in an intense flux of fast neutrons, unlike all semiconductor detectors whose performance quickly deteriorates from fast neutron damage.

These features also suggest a number of potential uses:

- At distances up to 100 meters, the sensitivity and energy resolution of the spectrometer are sufficient for the detection-of several kilograms of plutonium in a few minutes. Furthermore, the energy resolution is sufficient so that the isotopic composition of the material can be established (weapons-grade plutonium can be distinguished from that produced in a civilian power reactor).
- Experience with Brookhaven's CIVET (Controlled Intrusiveness Verification Technique) concept and equipment has demonstrated that each individual type or model of nuclear explosive device emits a unique gamma-ray "fingerprint," identifying that device and distinguishing it from other devices or items containing fissile materials. Similar fingerprints exist for other items containing nuclear materials. In many instances, this may satisfy DOE's requirement for a confirmatory measurement on plutonium (and in favorable cases, highly enriched uranium). Ordinarily, a high purity germanium gamma-ray spectrometer would be used, but under conditions where this is not convenient or feasible (for example at remote locations), the xenon gamma-ray spectrometer will suffice.
- An item of current concern is the continuous monitoring of a number of items stored in a vault or other storage location. The sensitivity and specificity of the xenon gamma-ray spectrometer for individual gamma rays is such that it should generate an alarm in a few minutes if one out of a substantial number of items is removed from its location. The superior energy resolution facilitates accurate background subtraction and would complicate "spoofing" of the system by other radioactive materials.

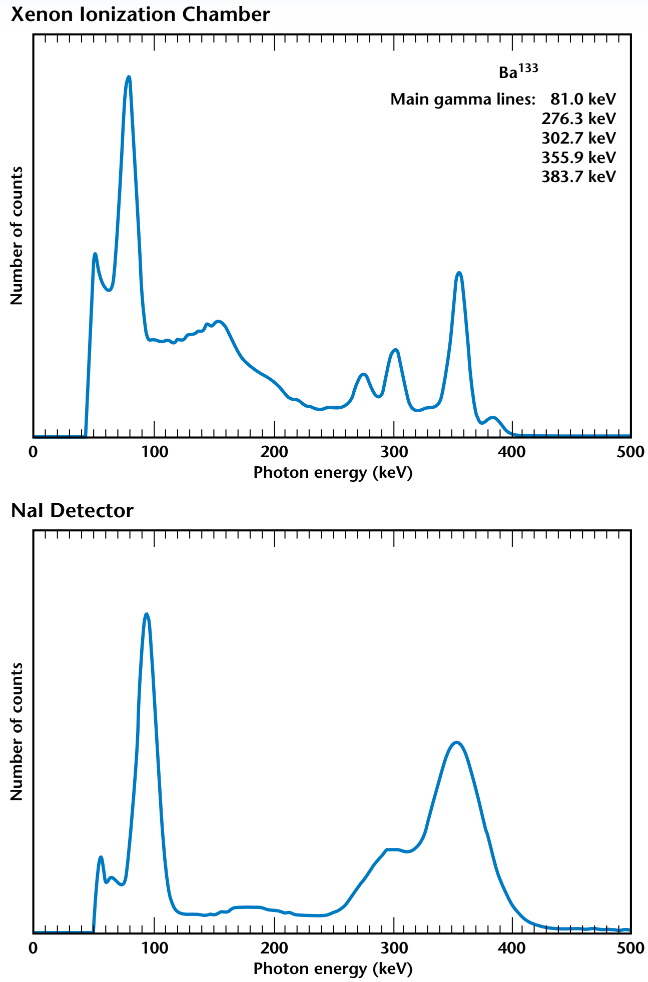

Figure 2. The spectrum of a ^{133}Ba source obtained by the Mark II spectrometer is compared to a spectrum of the same source obtained with a NaI scintillation spectrometer. In the top spectrum, obtained for a xenon gas density of approximately 0.4 g/cm^3, the individual ^{133}Ba peaks are well resolved, giving accurate areas for each peak. The energy resolution obtained for the 356 keV peak is 15 keV, a three-fold advantage over the scintillation spectrometer.

Monte Carlo Calculations of Gamma-Ray Spectra for Calibration

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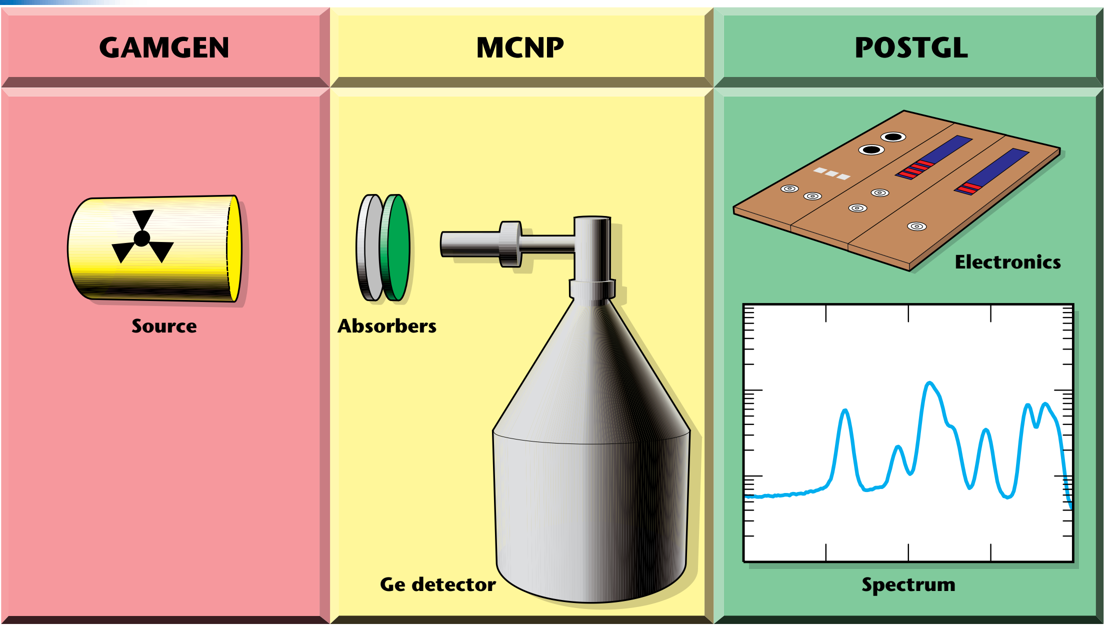

Figure 1. Three of the software programs for calculating gamma-ray spectra of SNM are pictured with the physical process and components they simulate: GAMGEN simulates the source, MCNP the geometry and physical interactions, and POSTGL the detector and electronics.

When special nuclear materials (SNM) are moved from one facility to the another, the amount of SNM moved is subtracted from the former's inventory and added to the latter's inventory. To ensure that identical amounts of SNM are shipped and received, the shipper measures the SNM prior to shipping, and the receiver measures again after receipt.

Shippers and receivers often determine the amount of SNM in a package with a gamma-ray energy histogram, or spectrum, from a germanium detector. The gamma-ray energies and intensities recorded in the spectrum are then analyzed by computer to accurately determine the isotopic content of the SNM. The performance of the detection system and the isotopic analysis software is calibrated using physical isotopic standards.

Unfortunately, the isotopic standards of SNM are difficult to make and certify, and therefore are costly. Computer simulation is a cost-effective, timely, and convenient tool to create gamma-ray spectra representative of isotopic standards. These simulations, while not substituting completely for physical standards, can help test and qualify isotopic analysis software; investigate questions of absorbers, collimation, and measurement geometry; study the effects of various mixtures of radioactive species on the assay; investigate the effects of nonuniform materials; and simulate the effects of electronic or detector degradation.

Gamma rays emitted from standard sources, the gamma-ray interactions with the detectors, the effects of electronics components, and the influence of the geometry in the measurement setup can all be simulated because the detailed physics of all the processes are well known. The Monte Carlo method—a "dice-throwing" sampling scheme—is used in computer simulations because of the probabilistic nature of the interactions involved.

We have developed a detailed simulation methodology with four main components: one each for the source, the detection geometry and gamma-ray interactions, the electronics, and our isotopic analysis software. Figure 1 shows the first three simulation components and the corresponding modules in an experimental measurement.

The source component is a database of gamma-ray data for SNM isotopes, and a computer program GAMGEN to calculate the radioactive decay of the isotopes, developed at the Lawrence Livemore National Laboratory. The geometry and gamma-ray interactions component is a user interface to create the input data for the Monte Carlo program, MCNP, the widely used Monte Carlo interaction program created by the Los Alamos National Laboratory. The effects of the electronic and detector response are simulated by a post-processing program POSTGL developed at Lawrence Livermore. Finally, SNM energy spectra—both simulated and measured—can be analyzed by Multi-Group

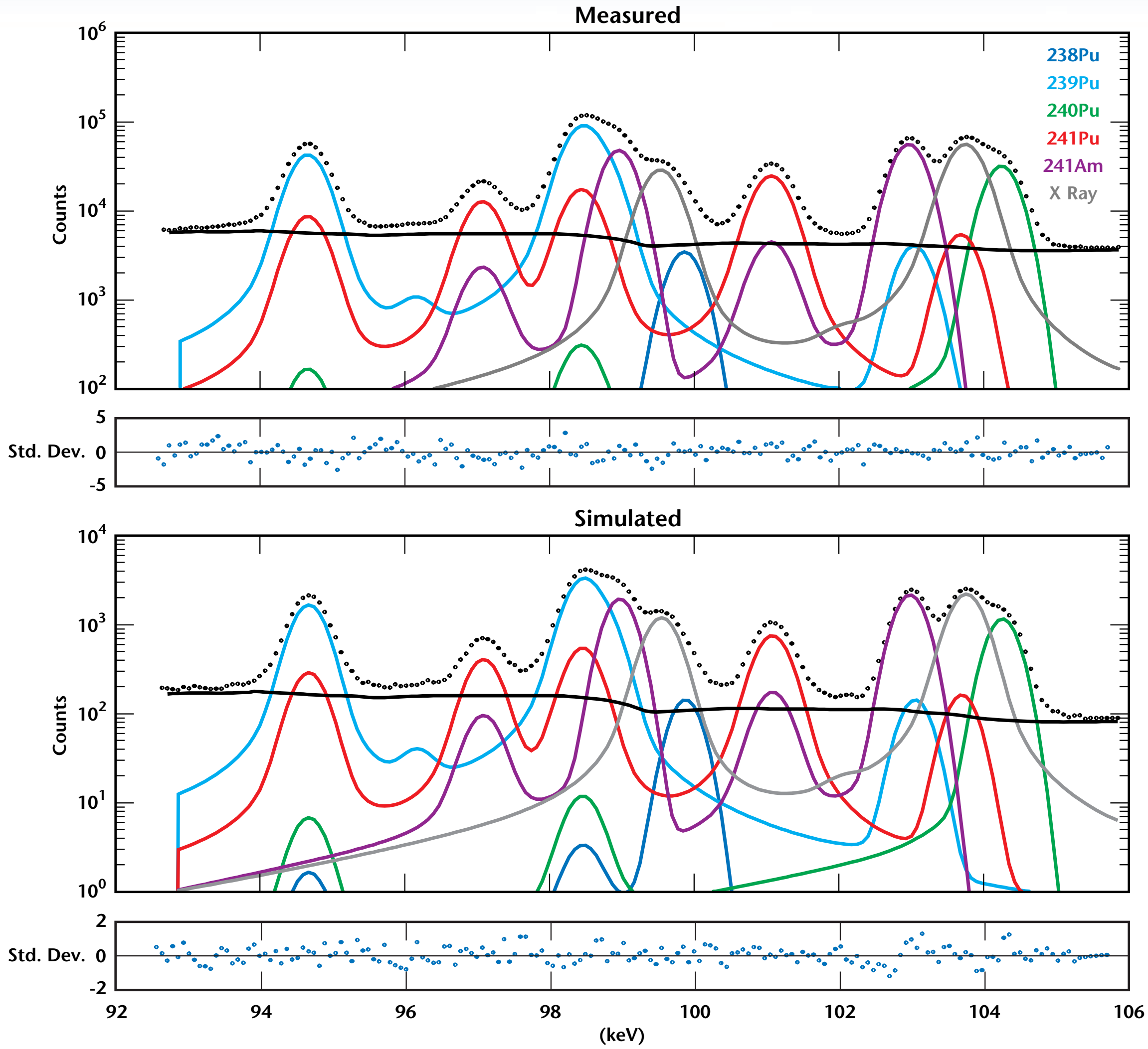

Figure 2. A measured spectrum of a plutonium standard is compared to the simulation of that standard spectrum. The MGA fits to those spectra are shown. The measured and simulated spectra give identical isotopes assays.

Analysis (MGA), an internationally used software package developed at Lawrence Livermore.

We have demonstrated that our methodology can successfully simulate plutonium gamma-ray standards with the ^{239}Pu enrichment ranging from 60% to 90%. For example, for one of our simulated weapons-grade plutonium gamma-ray standards, MGA reported identical (within statistical errors) isotopic contents for the measured gamma-ray spectrum and the computer simulation of that spectrum (Figure 2).

We are extending our methodolgy to simulate the gamma-ray spectra of uranium isotopic standards. With the completion of this effort, we can easily extend the methodology to calculate the spectra of mixed plutonium and uranium standards. Physical standards of such mixtures can be difficult to make because of the difference in the density between uranium and plutonium, and the desire to refrain from mixing SNM elements if possible. Samples of such mixed SNM do exist in the inventories in the United States. Simulating their gamma-ray spectra can aid analysts in choosing the correct software or measurement scheme.

Using the methodology we developed, anyone can install our simulation capability on his or her personal computer. A modern personal computer can provide a simulated spectrum sufficient to address questions such as the effect of a particular collimator or absorber in a few hours. A simulation calculated over a weekend can provide a gamma-ray spectrum that is almost impossible to distinguish from the measured spectrum of a physical standard.

Emission- and Transmission-Computed Tomography with Gamma Rays

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Figure 1. The scanner system consists of horizontal and vertical translation stages and a rotational stage. A double shield contains a plutonium button placed on top of the rotational stage. Lead collimators and a germanium gamma-ray detector are on the right.

We are adapting emission- and transmission-computed tomography with gamma rays for the nondestructive analysis of the special nuclear materials (SNM)—uranium and plutonium—in small, dense heterogeneous samples of the types stored throughout the Department of Energy complex. Computed tomography employing the transmission of gamma rays has been widely used in medical applications for more than a decade. We are extending this method by using the gamma rays emitted by the sample itself to measure a three-dimensional distribution of SNM so that heterogeneous samples, such as plutonium buttons from the molten-salt extraction (MSE) process, can be quantified.

In the conventional gamma-ray detection used to nondestructively assay SNM, the energies and intensities of gamma rays emitted from the sample are recorded by a simple detection system. The SNM content of the sample is then derived from the properties of the characteristic gamma rays. This technique relies on an important assumption: that the material in the sample is homogenous throughout, and therefore gamma rays are attenuated uniformly.

In many cases, this technique cannot quantitatively assay SNM due to the heterogeneous nature of the sample. For example, it is extremely difficult to accurately correct for gamma-ray attenuation when the uranium or plutonium is in lumps, or when the sample matrix itself varies in composition or density.

On the other hand, transmission-computed tomography, using external gamma-ray sources, maps out the *density distribution of the sample*. Emission-computed tomography, using characteristic gamma rays of the SNM, maps out the *location of SNM in the sample* . By combining these results, gamma-ray attenuation can be corrected throughout the sample so that the SNM in a MSE plutonium button, or similar sample, can be quantified.

Figure 1 shows our tomography scanner. A precision stage accurately translates and rotates the sample. During the emission-computed tomography, gamma rays emitted by the sample are collimated by a small, high-precision lead collimator onto a germanium detector. Controlled movement of the stages creates a three-dimensional scan of the entire sample.

During the transmission-computed tomography, a pencil beam of monochromatic gamma rays from an

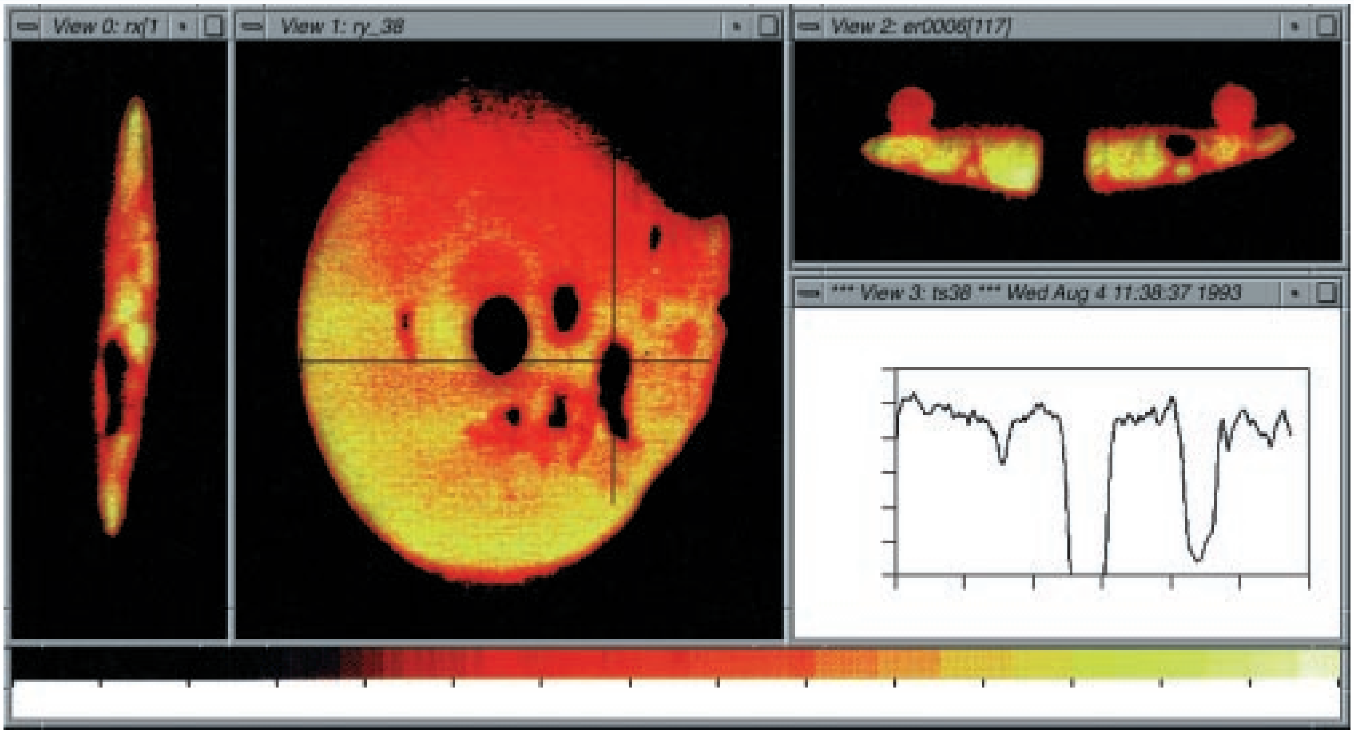

Figure 2. Three 2-dimensional slices centered on a void (dark area) of a transmission-computed tomographic image of a plutonium button from the molten-salt process. This void is completely surrounded by the plutonium and cannot be seen by visual inspection. The plot on the bottom right shows the relative attenuation through the horizontal cut of the center image.

external source are shown onto the sample. After traversing the sample and the collimator, they impinge on the detector. Once again, moving the stage allows for a full scan of the sample.

We concentrated on assaying MSE plutonium buttons during the development of the tomography method because they represent a large number of existing heterogeneous SMN samples. In the MSE process, plutonium present in the remnants from a variety of processes is recovered by extraction with a molten salt. Quantitatively determining plutonium in the resulting buttons using conventional gamma-ray detection is uncertain because the results depend on an approximate model that describes the distribution of the plutonium, the daughter americium, and salt residue within the button to determine the attenuation.

In the transmission-computed tomography approach, the effect of a nonuniform distribution is measured directly, eliminating the need for a model. Figure 2 shows three 2-dimensional slices of a transmission tomographic image of a MSE plutonium button, revealing heterogeneities within the sample that are difficult to detect and quantify by other methods. When we combine the transmission tomographic data with the emission tomographic data, we can obtain the distribution of plutonium and americium.

Segmented Gamma-Ray Scanner for Isotopic Analysis

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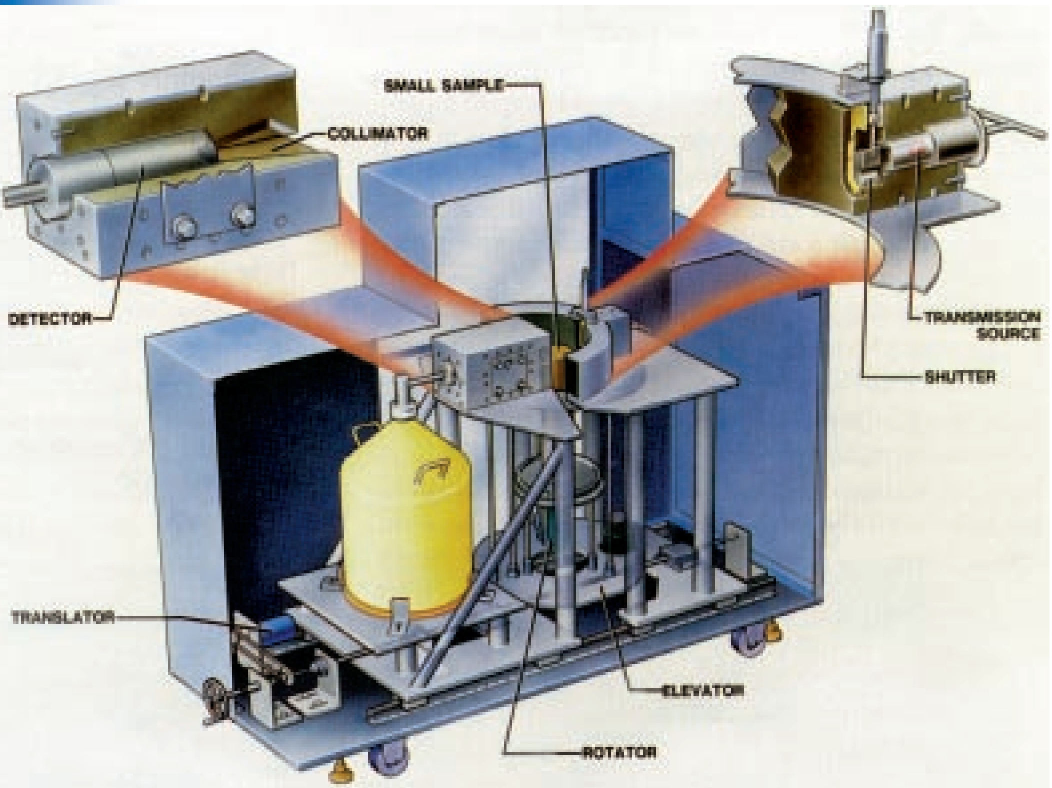

Figure 1. In the Segmented Gamma-Ray Scanner (SGS), segments of the sample (the small golden-brown waste container) are scanned by the transmission source (red) as the sample is raised by the elevator and turned about a vertical axis. Gamma radiation from the sample and the source is detected with a collimated germanium detector (gray).

As radioactive materials decay, they produce gamma radiation. Each specific material, such as a variant (isotope) of plutonium, produces gamma rays within a unique range of energy levels. In other words, each isotope has a unique gamma-ray fingerprint. A device called a Segmented Gamma-Ray Scanner (SGS) uses these fingerprints to scan containers of nuclear waste, determining the amounts of various materials within the containers.

Essentially, an SGS is a gamma-ray detector positioned above a turntable–platform that can be raised and lowered. A sample container, which may range in size from a few inches tall to a 55-gallon drum, is placed on the turntable. The platform's height is adjusted so that a section of the container is in front of the detector. (The detector's range of vision is limited by a sort of blinder known as a collimator; this collimator allows it to "see" only a segment of the container at a time, hence the name of the device). The container is rotated 360° as the detector measures the gamma-ray output. Then the container is raised so that the next segment comes into the detector's view, and the process is repeated until all segments are scanned. A computer attached to the SGS uses the intensity of the rays produced within the range of a preselected fingerprint to determine the amount of that material in the containers. Therefore, SGS operators must know what isotopes are in the container to measure the amounts of those materials.

Unfortunately, many waste containers from the earlier years of the nuclear-weapons and nuclear-energy industries have unidentified materials in them. Investigators at Los Alamos National Laboratory have developed software that will greatly enhance the usefulness of the SGS by identifying *types* of materials as well as amounts.

The software looks at the range of gamma rays coming from a source and compares them to a library of gamma-ray fingerprints. In combination with the detector, it functions in a way similar to the color-detection system of the human eye and brain. The eye takes in light and breaks it down according to the energy frequencies it can detect, and the brain interprets the frequencies as specific colors within the color spectrum. It is not limited to just looking for the colors blue and mauve, for example. The brain can also identify the intensity or saturation of the colors, similar to the SGS's ability to measure the intensity of gamma rays. With Los Alamos' new software, an SGS can

Figure 2. A segmented gamma-ray scanner can analyze a sample container (seen on the turntable) as large as a 55-gallon drum.

identify the material in a container and indicate how much of the material is within it.

A prototype SGS with the new software has already been tested at the Savannah River Site, and it correctly identified the compositions of approximately 100 samples containing mixtures of materials. The Los Alamos project now is working to simplify the software so that the average SGS operator can use it with ease.

Integrated Holdup Measurement System for SNM

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Figure 1. Holdup inside irregular pipe work is measured with the hand-held system developed by Los Alamos National Laboratory.

The Department of Energy's nuclear facilities regularly inventory their holdings of special nuclear materials (SNM). This is relatively easy when the SNM are stored in containers, but SNM collected in processing equipment (known as "holdup" material) are considerably harder to measure. The only reliable approach had been to shut the equipment down, flush it out, and count. This is costly and inefficient, and can expose workers unnecessarily to greater radiation levels. Los Alamos National Laboratory has developed hand-held portable detectors that allow technicians to measure SNM while they are still inside the equipment.

The system has three primary components: (1) a commercially produced gamma-ray detector, housed in a metal cylinder similar in appearance to a microphone; (2) a controller that stores data and downloads it to a computer; and (3) software for the computer that analyzes the data. Radioactive materials emit gamma rays as they decay. The detector measures the strength of the rays at each sample location, and the controller records those measurements along with the locations. This part of the new detector is like any other gamma-ray measuring device, but in most devices, the sample is in a container with a fixed geometry—a cylinder or a box—and located at a fixed distance from the detector. It is a challenge for a hand-held system to measure SNM within any number of geometric shapes and at varying distances.

Contrast the following examples. A layer of liquid SNM is poured onto a flat surface. The detector is held close to the materials. Because it is enclosed by a cylinder, the detector "sees" a small circular portion of the materials. Because gamma rays—like all rays—dissipate in strength at a given rate for each unit of distance from the source, and because a given amount of a specific SNM emits a given number of gamma rays, a computer can calculate the amount of SNM given the distance and the energy count. If the detector was moved further away from the liquid, only the distance has changed. The computer can still calculate the quantity by allowing for the greater distance.

What if the material sits in a pipe? When the detector moves far enough away from the pipe, the SNM will only be taking up a portion of the circle seen by the detector, the portion defined by a line the width of the pipe's interior. If the computer does not know that, and assumes the measurements came from the detector's complete field of view, its calculations will be inaccurate. Although equipment takes many forms, Los Alamos has achieved acceptable measurement accuracy by defining the geometry at each location as one of three basic, two-dimensional shapes: a circle, a line, or a point.

Barcoding the sample locations, automating data readouts through the controller, and establishing a set distance at each location greatly simplifies the measurement process. This approach allows quick holdup assays in the miles of duct work, hundreds of valves and pipes, and dozens of pieces of equipment within a single plant. Its value has been thoroughly tested and proven, and although Los Alamos continues to develop and improve these detectors, some units are already being used at the Y-12 Plant.

Development of Advanced Isotopic Analysis Software

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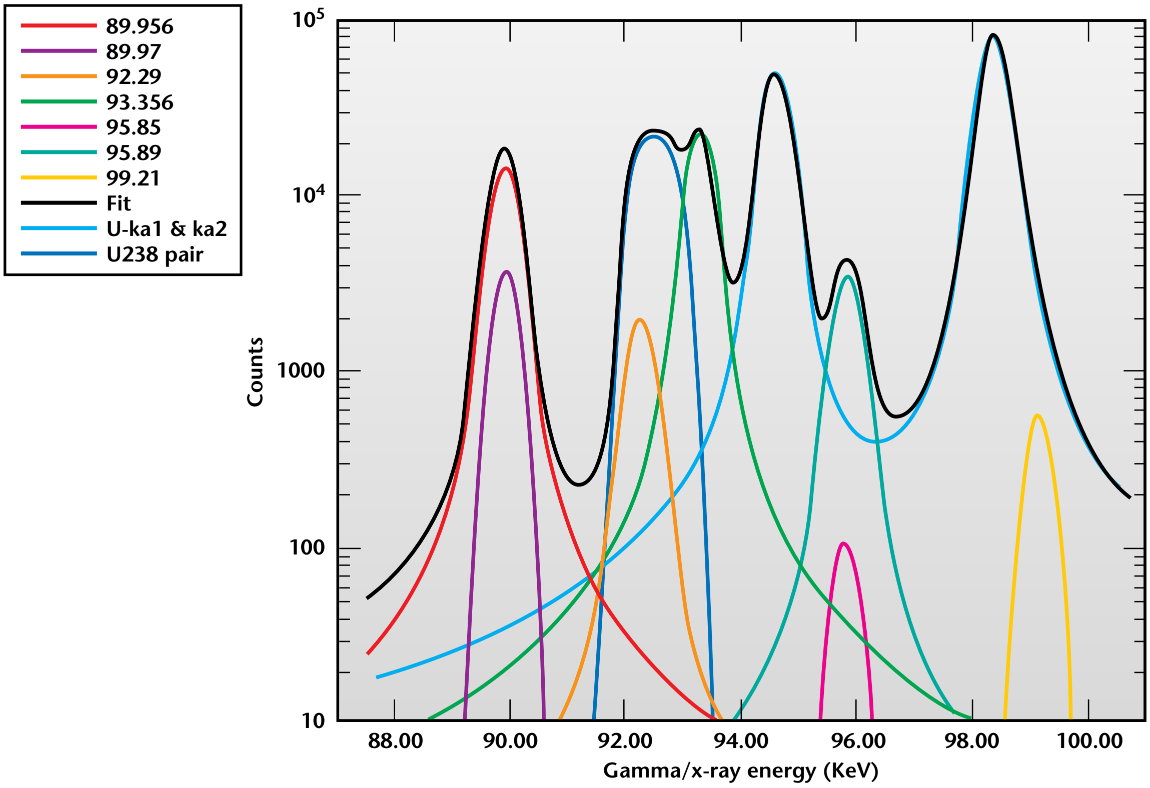

Figure 1. Uranium isotopic analysis using 100-keV region.

We are developing isotopic analysis software to address a a wide variety of applications and requirements in nondestructive analysis (NDA) of special nuclear materials (SNM) using gamma-ray spectrometry. Requests to analyze SNM samples with unusual isotopic composition, contamination, sample heterogeneity, or nonstandard containers made us aware of the need for more flexible and robust analysis software.

The Multi-Group Analysis (MGA) program—our current gamma-ray analysis software for NDA—has a long track record of providing high-quality isotopic data analysis (Fig. 1). MGA works extremely well for homogeneous samples that do not contain unusual isotopics. We have modified the MGA program to extend its plutonium isotopic analysis capability to samples with greater ^{241}Am content, or that contain uranium. Our project focuses on needs presented by new analysis problems not addressed by MGA. In addition, our new software is based on a modular design to avoid deficiencies in MGA such as difficult maintenance.

MGA++, our new analysis software, will perform the functions of MGA over a wider envelope of isotopics, interferences, sample matrices, and counting conditions, and will also analyze some new sample types. Thus, MGA++ not only will analyze ^{235}U and ^{238}U over a wide enrichment range, but it will also analyze samples enriched in ^{238}Pu, mixed metal/oxides, and shielded samples.

MGA++'s performance requirements include reliability and accuracy using MGA performance as a baseline. Ease of modification and enhancement are also required so that the software can address new analysis problems in a timely manner.

MGA++ is also designed to have different modes of operation depending on the skill level of the user. Operators in the field can run the code in an automated fashion, or it can run automatically during unattended operations. Experienced analysts and developers can run the software interactively. It will also run in a highly interactive diagnostic mode for developers.

The client–server architecture of MGA++ is a collection of cooperating processes. These processes might all be on the same computer or they might be distributed over a

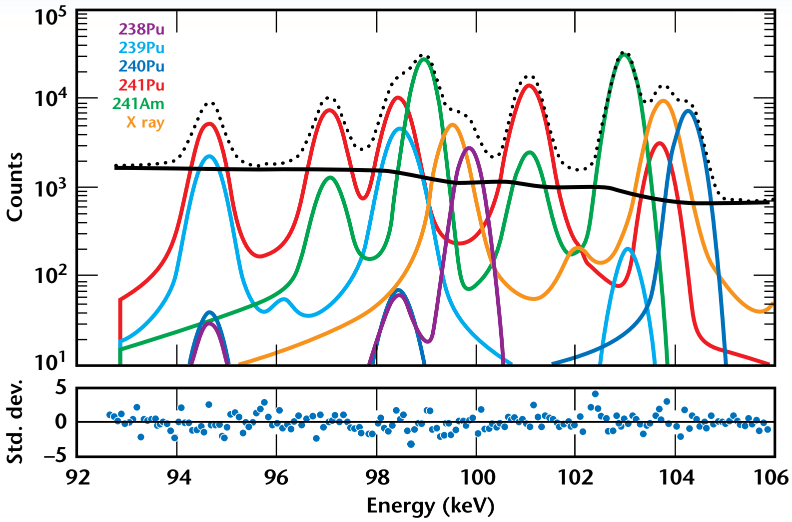

Figure 2. Plutonium isotopic analysis using 100-keV region.

network. The architecture allows an extensive collection of modules and functions to be assembled to address specific tasks quickly and relatively simply. It also allows the individual parts to be simple and independent of other parts of the system. This architecture requires an operating system that supports multi-tasking, such as Windows 95,™ Windows NT,™ Unix, or OS/2.™

The MGA++ executive is the primary client for the user. It communicates with the SpecView graphics server, the inference server, the analysis servers, and other instruments or systems. The MGA++ executive is the controller of the isotopic analysis and manages all interprocess communications between itself and the various servers. It is the basis for automated analysis under a wide variety of isotopic, sample, and counting conditions. It will allow the analysis process to be audited, and the operation of the code to be verified.

The executive communicates with an inference engine that has a database of analysis rules and knowledge of how isotopic analysis is best performed under various conditions. The prototype for this engine has demonstrated the ability to chose between plutonium analysis or uranium analysis without any input from the user.

The SpecView server implements the graphical user interface. It plots spectral data and the results of the fitting process (Fig. 2).

The spectral analysis process determines the intensity and energies of the gamma-ray photopeaks measured by the detector. After various physical corrections have been applied, these quantities determine the relative isotopic ratios of the radioactive components of the sample.

Because of our "tool-box" approach, we are approaching commercialization without the need to transfer source code or co-develop software. We will provide an application programming interface to vendors interested in licensing. They will provide the interface that integrates the MGA++ analysis software into their proprietary data collection and viewing environment. They would provide their own user interface to the operation of MGA++. This way, we will retain control of the technology to simplify both later enhancements and in-depth technical support issues.

Prototype Tomographic Gamma-Ray Scanner

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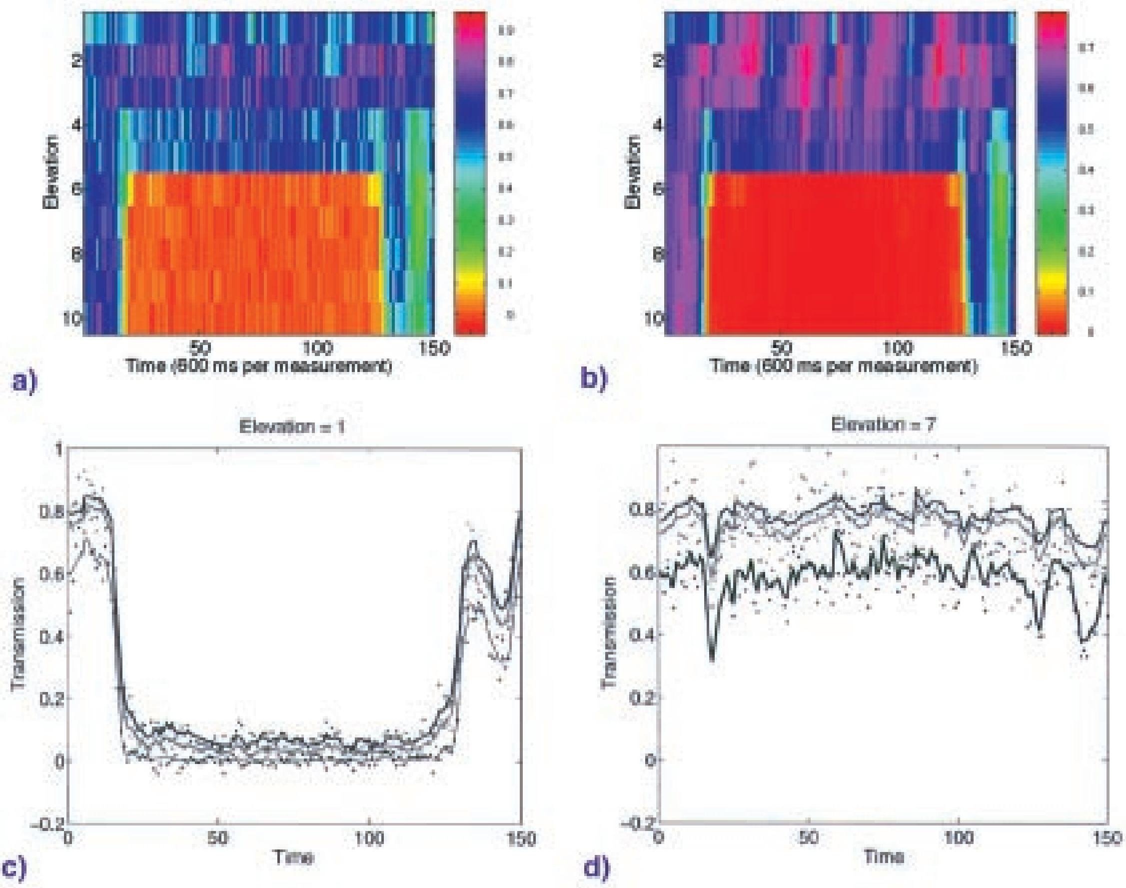

Figure 1. The Tomographic Gamma-Ray Scanner (TGS) works like a medical tomographic scanner, representing the object (in this case, a container) as a three-dimensional volume. The location of special nuclear materials in the container are revealed “slice by slice.”

Because the Segmented Gamma-Ray Scanner (SGS) moves in only two dimensions, calculations performed on SGS measurements must assume a uniform distribution of the special nuclear materials (SNM) and surrounding materials in a measured segment of the container. The SGS spins a container and moves it up and down. Because it cannot be sure of the *volume* of an SNM source—volume requires a three-dimensional image—its results can be significantly off in large containers or in small ones with dense materials. Similarly, if the surrounding material or “matrix” has a variety of materials blocking gamma-ray emissions at varying rates, the SGS can be off by as much as a factor of two. By adding a side-to-side motion, a tomographic gamma-ray scanner (TGS) can specify the location of the SNM and more easily correct for biases inherent in gamma-ray scanning.

Los Alamos National Laboratory has developed a TGS and continues to improve its performance. Like the SGS, the TGS has a platform that elevates and spins a container, a germanium gamma-ray detector, and a collimator to restrict the detector’s “range of vision.” The TGS also moves the container from side-to-side. Just as a medical tomographic scanner, for example, represents the brain as a series of three-dimensional slices, the TGS can “slice up” an SNM container to show where the SNM is within it. This allows the SNM’s volume and the different effects of heterogeneous matrix materials to be specified. Unlike a medical scanner, which cannot measure the quantity of the object it is viewing, the TGS also measures the quantity of SNM through its gamma-ray emissions.

Powerful calculating programs based on experiments with a prototype TGS are being written that can identify and quantify SNM in a container, regardless of their types or sizes or the types and characteristics of the matrix materials. Significantly, the TGS also measures plutonium in “shots” so dense they can bias their own measurements. Shots are the end products of an important method used to isolate and store plutonium.

With less assumptions to make, the measurement process is much quicker. An SGS takes 20 minutes to measure 16 segments of a container, the TGS can measure 2,500 segments per hour.

Its capabilities make the TGS the first truly general method of nondestructive assay of SNM: it doesn't care where the sample is in a container, how big it is, or what matrix it is in. The TGS can find, identify, and quantify the SNM, and do so faster and at accuracies acceptable for most purposes than any competing process. The result is a potential savings to taxpayers of millions of dollars per year.

Neutron-Induced, Gamma-Ray Signatures for Safeguards Applications

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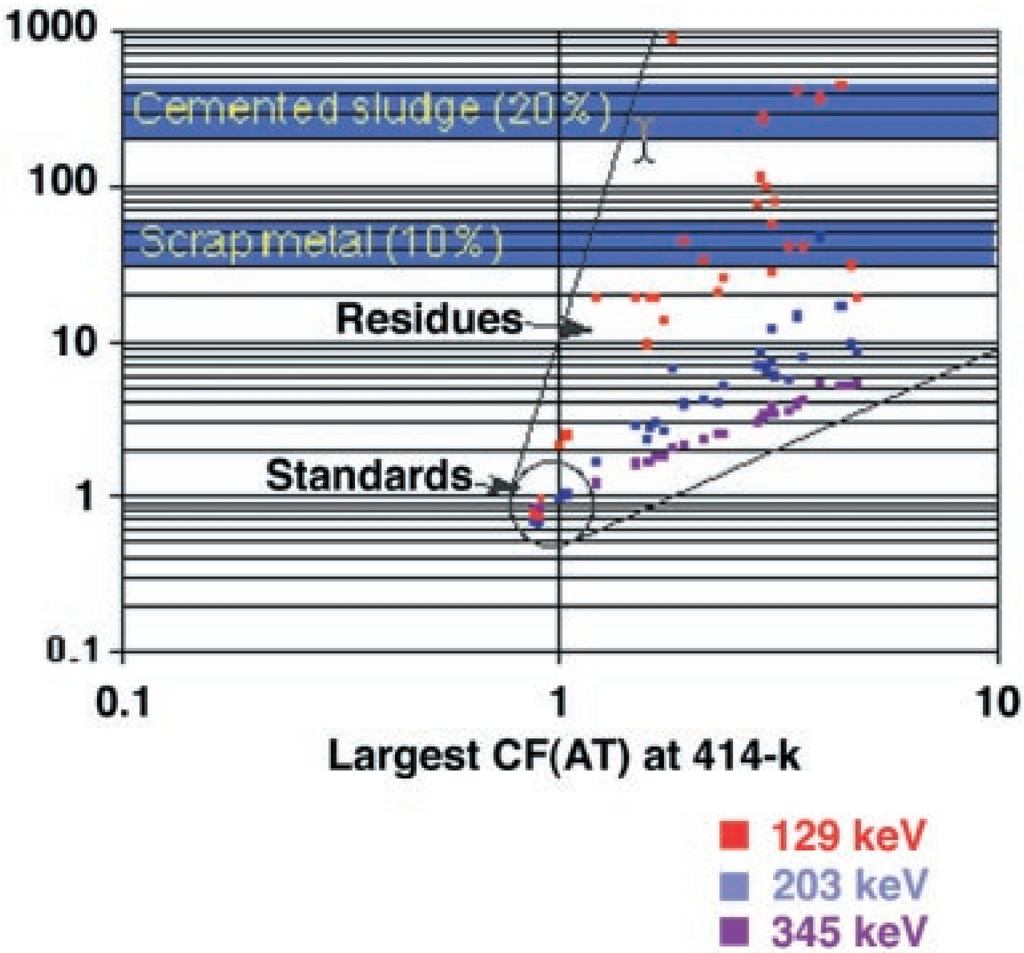

Figure 1. A library of gamma-ray "signatures" can help characterize containers of special nuclear materials, reducing the need for destructive analysis.

Nondestructive assays (NDAs) of special nuclear materials (SNM) suffer from attenuation—the tendency of some elements to capture or scatter the gamma rays and neutrons measured in NDA. Los Alamos National Laboratory is trying to improve the results from these assays by mapping the gamma-ray signatures of various attenuating elements to help correct for the biases caused by attenuation.

A primary focus of the research is "prompt" gamma rays. When a material is bombarded with neutrons, in some cases the nucleus of an atom will "capture" a neutron. The new atom is left in an excited state and emits gamma rays characteristic of the given element. A library of these gamma-ray "signatures" would help characterize drum contents, identify materials that could shield SNM, and measure the neutronic properties of the attenuating materials ("matrix") in a container to correct the moderation and absorption of neutrons.

The signatures could also help screen for hazardous and radioactive materials that produce weak results in standard assays, enabling more efficient categorization of waste and reducing the need for destructive analysis. For example, the concentration of technetium-99, a radioactive fission product, must be known before waste containing it can be disposed. However, technetium-99's neutron and gamma-ray emissions are so weak, they cannot get through surrounding materials, and thus it must be measured by nondestructive assay. Prompt gamma rays from this material, however, can penetrate NDA detectors because of their higher energies.

Finally, this method would be useful for verifying the amount of moisture in plutonium oxide, which must be done before these oxides can be placed in long-term storage. Moisture is difficult to measure because it is often part of the surroundings. However, the hydrogen in moisture can stop dead or wildly deflect the neutrons used in standard techniques. When hydrogen captures a neutron, however, it emits a specific gamma ray whose intensity correlates to the amount of moisture. In fact, in practical applications, hydrogen is the primary contributor to neutron moderation and so moisture can cause serious bias in active neutron assays even at relatively low concentrations.

Los Alamos has examined these applications of gamma-ray signatures using an existing instrument, essentially a germanium gamma-ray detector clad in a bismuth-germanium-oxide detector. The former detects the initial event; the latter detects the secondary ones. Through a combination of experimental results and sophisticated calculations, we are developing a library of gamma-ray signatures for elements of interest to safeguards operations.

Neutron Measurement Control

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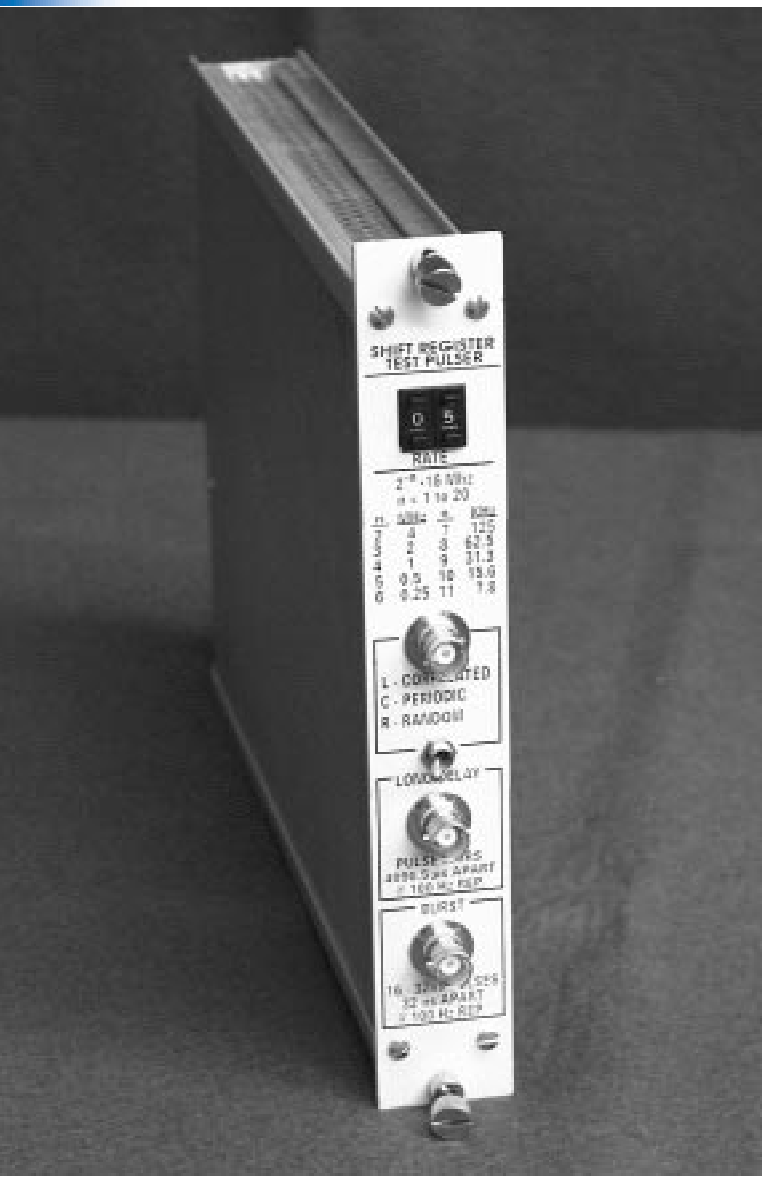

Figure 1. A prototype pulse generator developed by Los Alamos National Laboratory tests shift-register coincidence electronics, improving the accuracy of thermal neutron coincidence counters.

Thermal neutron coincidence counters are used extensively for the nondestructive assay of special nuclear materials (SNM), mostly plutonium and enriched uranium. Los Alamos National Laboratory has been improving the measurement control of these neutron counters. Here, measurement control means the application of various techniques to ensure that the neutron counters are operating properly.

The first area of improvement is calibrating the neutron counters using ^{252}Cf reference sources. The absolute yield of ^{252}Cf sources is the basis for most detector-efficiency calibrations. Because ^{252}Cf sources emit correlated neutrons from spontaneous fission and are readily available, are low cost, and have a well-known half-life, they are ideal for cross-calibration and measurement control of neutron counters. We had two ^{252}Cf reference sources calibrated at the National Institute of Science and Technology (NIST); the absolute yield accuracy is 1.4% (1 standard deviation). Twelve new ^{252}Cf sources, arriving during the summer of 1997, will be cross-calibrated with the reference sources measured at NIST. Cross-reference measurements are also being done between these sources and plutonium and americium–lithium reference sources.

The second area is upgrading and commercializing a random pulse generator to test coincidence electronics packages in the neutron counters. We have built six prototype pulse generators to test coincidence circuits. The prototype pulse generator produces random and several fixed correlated pulse streams designed to test all of the digital circuits of the coincidence electronics to their limits of performance. At present, tests are performed manually. Pulse generators are better than detectors for testing coincidence circuits because they test only the electronics, are more thorough, and can be done anywhere. Neutron sources are better used to test the detectors themselves.

The third area is developing and commercializing a correlated pulse generator to simulate neutron-detector pulse streams by generating arbitrary pulse streams under computer control. This pulse generator besides allowing the automated testing of coincidence electronics will have two side benefits: (1) the possibility of automated software testing, and (2) use in software development and training. The prototypes will be plug-in boards for personal computers, but stand-alone pulse generators should be practical. A stand-alone pulse generator could be part of a neutron counter, connected between the assay computer and the coincidence electronics; in this situation, the pulse generator would be an excellent instrument for automated hardware and software quality control testing.

The fourth area, an add-on to the original project, is developing and evaluating a dual-gated, shift-register coincidence electronics package. Although not specifically a measurement control project, it does improve measurement under our definition of measurement control by reducing the counting errors. A prototype has demonstrated that a significant improvement in precision is possible using this circuit.

Shuffler Waste Matrix Correction

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Figure 1. A shuffler for 55-gallon waste drums is being loaded. The double doors are closed and the assay is completed in 16 minutes. The ^{252}Cf source of neutrons is located in the shielding block above the drum.

Shufflers assay the mass of a fissile material by irradiating the material with a compact but intense source of neutrons (^{252}Cf) to induce fissions. Delayed neutrons emitted by fission products are counted after the source has been removed. This technique is most appropriate for materials with a weak spontaneous neutron emission rate (such as ^{235}U), but it is also used for strong emitters (such as plutonium) when other spontaneous emitters are present that are not readily fissioned by external neutrons (such as curium). Shufflers are used for small quantities of waste and large production quantities of fissile materials.

Shufflers are generally very precise and accurate instruments, but under some combinations of circumstances, the accuracy can be adversely affected. When a large waste container is filled with a hydrogeneous matrix (e.g., paper, rubber gloves, and plastics), the count rate from a localized fissile material will depend on the position of that material within the matrix. For example, the count rate from a position near the center of a drum of paper will be higher than the count rate from a position near the edge of the drum. (Drums with nonhydrogenous matrices, such as iron, do not have this problem.) To ensure that an assay is not an underestimate, it must be assumed that the fissile material is in the most unfavorable position and the amount of that material increased accordingly. This means that a drum may be considered to have much more fissile material than it actually does. This is very important for domestic waste because an overestimate of the amount of fissile material can cause a drum to be handled in a more expensive manner than necessary; an underestimate can cause a drum to be given an improper disposition.

The solution is to deduce the position of fissile material in such a drum and make an accurate correction for the position, if a correction is needed. Such a position determination can be made from the relative count rates in the shuffler's detector banks surrounding a waste drum if the drum is held stationary in several orientations during irradiations by the ^{252}Cf source. The volume of a drum is divided into many cells of equal volume; a correction factor for each cell is deduced empirically and applied to the uranium mass found from an assay.

This procedure has been demonstrated on an installed shuffler at Los Alamos National Laboratory and the final software is being written. The operators manual at Los Alamos will include this new measurement option. This process is available for future shuffler technology transfers; the hardware and existing software have already been transferred to a private company for the fabrication of three shufflers.

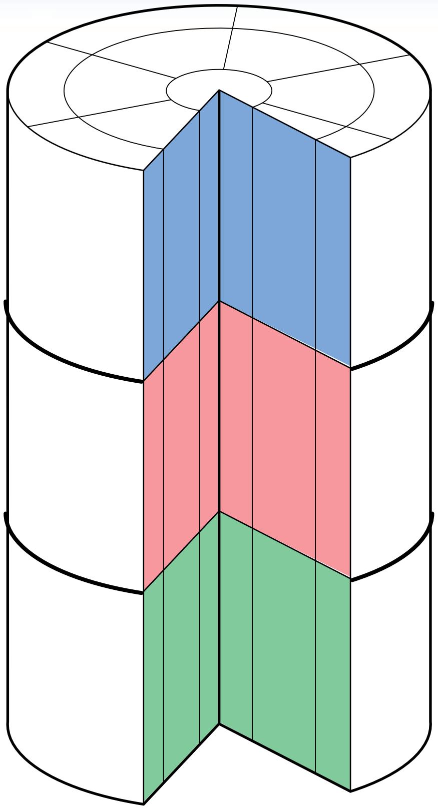

Figure 2. A 55-gallon waste drum is split into 39 cells, each with the same volume. Each of three vertical layers has 13 cells. The apparent mass of fissile material is found for each cell, and then a correction factor for each cell is applied to find the true mass.

Neutron Coincidence Software

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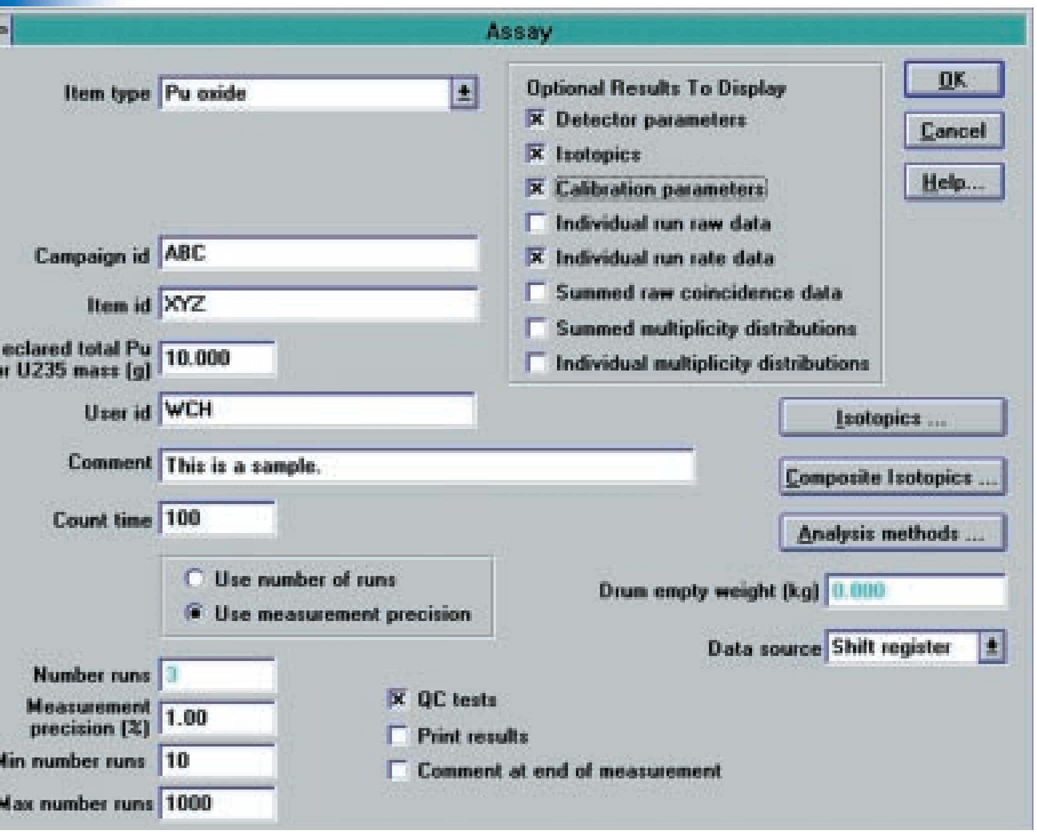

Figure 1. A representative screen from the Neutron Coincidence software shows a dialog box from an plutonium oxide assay.

Los Alamos National Laboratory developed software during a five-year project to assay special nuclear materials (SNM) using a technique called neutron coincidence counting. Fission rates in nuclear materials are determined by measuring the fission neutrons in coincidence and then calculating the mass of the nuclear material from the fission rates. The instruments used in this type of assay are called thermal neutron coincidence counters. The detection mechanism is neutron capture in ^{3}He proportional counters, embedded in polyethylene to increase the detection probability by thermalizing the neutrons. Special coincidence electronics process the neutron pulses from the detectors.

Plutonium is assayed by measuring its natural neutron emission (passive assay); uranium is assayed by inducing fissions with isotopic neutron sources (active assay). Dozens of detector designs are used worldwide to measure nuclear fuel materials, nuclear weapons materials, excess fissile materials, waste, etc. Most of these detectors and electronics were designed at Los Alamos; some of these are now commercially available.

The software is used with any of the detectors and electronic packages designed for neutron coincidence counting. The software is designed for Microsoft Windows and runs under Windows 3.1, Windows 95, and Windows NT. All of the procedures normally used in thermal neutron coincidence counting are included. Users can calibrate measurements, do least-squares fitting to obtain calibration curves, do assays, plot and print results, do quality-control tests, set measurement parameters, transfer data, etc. all within the program. All coincidence electronics packages developed to date are supported by the software.

Domestic users of the software include Los Alamos, Savannah River, Rocky Flats, Hanford, and Livermore. Custom variations of the program have been written for special situations. For example, a custom version was prepared for ARIES (Advanced Retirement and Integrated Extraction System) at Los Alamos, where an interface was needed between the neutron software and a host computer that controls all of the nondestructive assay instruments. A major variation is being prepared for the International Atomic Energy Agency, a major user of neutron coincidence counters.

Standards and Calibration for Nondestructive Assay Techniques

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Figure 1. Standards such as the ones seen here calibrate nondestructive analysis instruments and ensure measurement accuracy. Standards often come in sets with variations on a theme such as plutonium standards with different isotopic compositions.

In the last decade, nondestructive assay (NDA) techniques have become important analytical tools for identifying and measuring quantities of special nuclear materials (SNM). NDA has the advantage of being cheaper and more timely than destructive analysis, requiring less training of the operators, and not generating any hazardous or radioactive waste. In some cases, NDA is the only method for determining SNM content with reasonable accuracy.

Los Alamos National Laboratory is developing a practical guide for NDA users on the construction of materials used as calibration standards. As part of the project, Los Alamos also supports Department of Energy facilities in the creation of calibration standards. While many papers and books have discussed NDA techniques, very few have been devoted exclusively to NDA standards. Most NDA techniques rely on standards, a representative sample of a given material, for calibration. By comparing an NDA instrument's response to a standard to that for an item being measured, operators can ensure that the measurement is accurate. NDA standards are a crucial part of any NDA assay technique.

For any given material, an NDA standard must be of a physical size, SNM mass, and chemical form applicable to the NDA technique being calibrated. Good calibration defines an absolute or relative relationship between the NDA instrument's response and the masses or ratios of SNM nuclides known to be present in a sample. Calibration takes into account the technique's efficiency, materials that might absorb the phenomenon being measured, and any other factor that affects the response of the system. The preparation of an NDA standard is expensive and time-consuming. If a set of standards is prepared incorrectly, it is a waste of both time and money; in addition SNM waste is generated that must be disposed of or recovered.

Los Alamos' major activity is preparing a publication, *Guidance for Construction of Calibration Materials for NDA*. For each NDA technique currently in use, the report includes sections on measurement principles and physical criteria for standards. These lead to sections on the preparation and descriptions of examples. There is also information on available NDA standards and the use of simulations as alternatives to standards. The publication will be released this year.

Additional activities include discussions with the Savannah River's planned Actinide Packaging and Storage Facility, where NDA systems will include calorimeters, neutron multiplicity counters, and gamma-ray spectrometers; support for Lawrence Livermore's Active Well Coincidence Counter, a californium shuffler, and 30-gallon multiplicity counter that the facility acquired to verify previously unmeasured inventory; and several programs for standards fabrication at Los Alamos' Plutonium Facility.

Radiometric Calorimetry

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Figure 1. An in-line calorimeter is installed under the Advanced Recovery and Integrated Extraction System (ARIES) robot.

Radiometric calorimetry is a nondestructive assay technique to determine the thermal power output of heat-producing nuclear materials. The heat in these materials results from the thermalization of their radioactive emissions, such as alpha, beta, and gamma radiations. Precision calorimeters determine the power output (Watts) of various radionuclides over a broad range of power levels and sample types. Systems have been manufactured to measure the thermal power from 0.00020 to 1000.0 Watts for samples ranging from 0.5 to 13.0 inches in diameter and up to 24.0 inches in length. Sample types have ranged from aqueous waste to weapon components.

The Office of Safeguards and Security, in the Department of Energy, has supported this unique calorimetry development at Mound Laboratories in Miamisburg, Ohio. For over 40 years, Mound scientists and engineers developed, designed, fabricated, tested, installed, and serviced customized calorimeter systems and also trained people in their operations. Some Mound staff, calorimeters, blueprints, and other documentation have now been transferred to Los Alamos National Laboratory as part of DOE's Nonnuclear Reconfiguration Program. Transfer of technical knowledge and the training of Los Alamos personnel is assisted by senior Mound consultants. In September 1996, the new temperature- and humidity-controlled Calorimetry Lab at Los Alamos was completed, and several developmental calorimeters are now being tested.

Los Alamos will now support DOE facilities by providing prototype calorimeter systems with integrated hardware, electronics, and software. Each system will be thoroughly tested before leaving Los Alamos to ensure compliance with customer specifications. After the system is delivered and set up at the facility, Los Alamos will assist in acceptance testing and operator training. Operating manuals, software manuals, and equipment manuals will be supplied with each system. After installation, Los Alamos calorimetry specialists will consult in data analysis or in resolving calorimetry problems.

Los Alamos will develop new calorimetry innovations for more cost-effective facility safeguards, such as custom-designed calorimeter systems that can be transported, installed under gloveboxes, or permanently mounted in process areas. These systems will include Windows-based software for easier operation and data analysis. To provide routine, long-term support to DOE facilities, Los Alamos will also transfer calorimetry technology to the commercial sector.

In addition, Los Alamos will offer two CTA-registered training courses originally developed at Mound. The once-a-year "Calorimetric Assay" seminar will cover all of the aspects of calorimetry and gamma spectrometry required to obtain grams of plutonium, tritium, or other nuclear materials in a sample. The "Calorimeter Operator" course will provide site-specific training at any DOE facility.

The ^{238}Pu heat-standards-calibration calorimeters from Mound will be available in 1997 at Los Alamos to provide National Institute of Science and Technology-traceable calibration and certification of heat sources. Los Alamos will work with DOE facilities to repackage heat sources into ANSI-certified containers to make future shipping and certification activities easier to accomplish.

Figure 2. A Mound Laboratories heat-standards-calibration was transferred to Los Alamos National Laboratory in September 1996.

Automated Pu(IV) Spectrophotometric Method

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Figure 1. The automated Pu(IV) spectrophotometer includes a computer controller, guided-wave spectrophotometer, and software to analyze samples set in a containment box.

The most accurate method for measuring special nuclear materials (SNM) in a solution is spectrophotometric evaluation. Light is shone through a chemically prepared solution, and the spectrophotometer measures the wavelengths absorbed by the substances within. That result is compared to a test run using a *standard*, a stable solution with a known amount and type of SNM. The difference determines what is in the sample solution. The analysis is accurate even in solutions with small amounts of SNM, or containing large varieties of materials. Because of its accuracy, this method also is ideal for creating standards for other nondestructive assay techniques.

As material is removed from storage for environmental cleanup, the ability to accurately measure these materials rapidly becomes increasingly important. To that end, Los Alamos National Laboratory developed a prototype to automate the spectrophotometry process to improve turnaround times, reduce generation of liquefied waste, reduce radiation exposure of workers, and reduce errors.

The spectrophotometry method has three primary steps: (1) the taking of samples for testing, (2) chemical preparation of the samples, and (3) measurement. The first two, project scientists decided, were labor-intensive but not particularly time-consuming. The third step required little operator effort, but it took time as the operator waited for a sample to be measured before introducing the next sample. Therefore, automating the measuring process seemed the most likely candidate to save time and therefore cost.

Los Alamos reworked the software used by its spectrophotometer, using the autoscan and autosave features to replace some manual operations without losing reliability and precision. A pump was added to replace the manual vacuum-assisted method of introducing samples into the test cell, again without losing precision. Finally, an autosampler was added to automate the introduction process. By purchasing the computer code that controlled the spectrophotometer, we were able to incorporate the software for the pump and autosampler, and integrate control over the process.

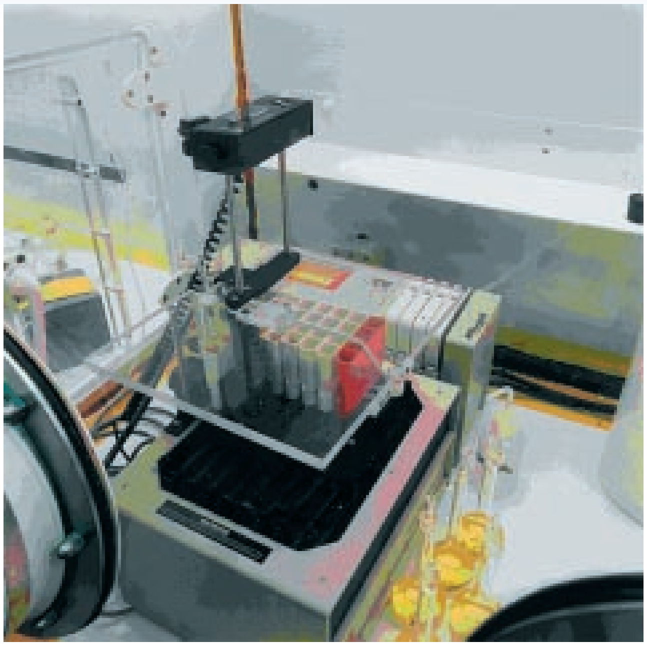

Figure 2. The autosampler and pump cut down on operator time.

Hybrid K-Edge/XRF Densitometer for Assaying Solutions

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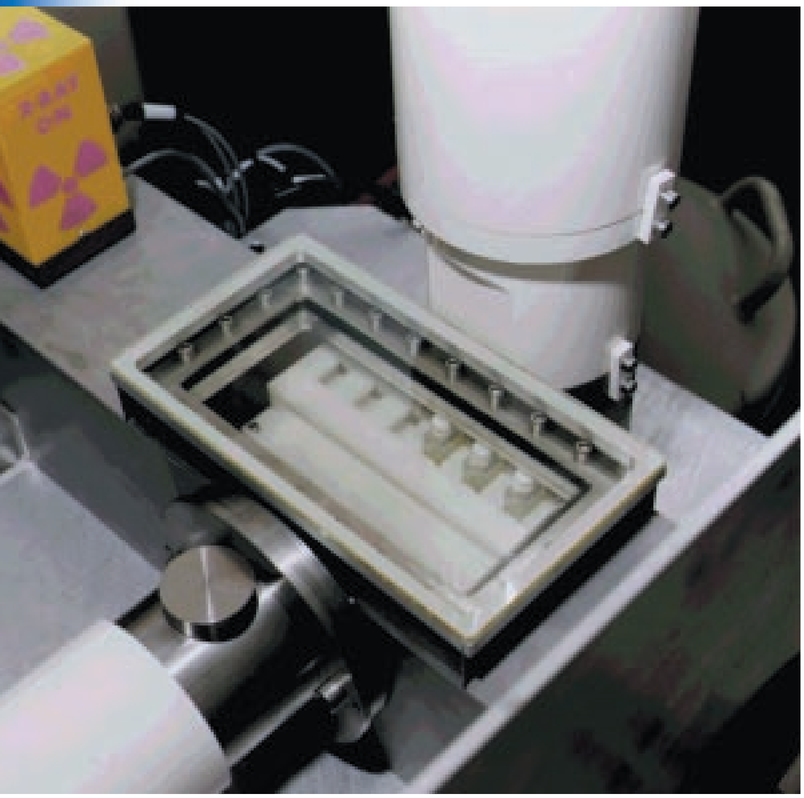

Figure 1. The hybrid densitometer combines K-edge absorption and x-ray fluorescence (XRF) to measure ratios of special nuclear materials in solution. The vertical cylinder on the right houses the x-ray tube. The x-ray beam shines through the collimator and the solution sample. The K-edge and XRF detectors are housed underneath the sample tray visible through a glass window in the center of the photo.

Among the byproducts of nuclear reprocessing plants are solutions of uranium and plutonium. A device developed over the last ten years known as a hybrid K-edge/XRF densitometer (HKED) has become an important tool for measuring these elements in solution. Analytical laboratories produce solutions of special nuclear materials (SNM) as well, but the ratios and concentrations are significantly more varied. Because the HKED was developed for reprocessing applications, the technique was of little use in the laboratory.

The Japan Atomic Energy Research Institute (JAERI) needed a tool like the HKED that measured solutions produced by analytical laboratories, as part of routine assays for international inspections. Los Alamos National Laboratory developed one for JAERI and is developing a similar HKED for the Plutonium Facility at Los Alamos.

The hybrid instrument combines the strengths of two different techniques—K-edge absorption densitometry (KED) and x-ray fluorescence (XRF)—to determine concentrations of uranium and plutonium and the ratios of the two elements in solutions. KED has the advantage of relatively stable calibration; but, it does not have a wide dynamic range. In mixed solutions of uranium and plutonium, the isotope with the lower concentration cannot be determined precisely by KED when the concentration ratio exceeds 10. KED results are determined by the absorption of x rays sent through the sample solution; when the ratio exceeds ten, the absorption due to the minor element is almost negligible.

XRF results are based on electromagnetic releases caused when the x rays excite the uranium and plutonium atoms in the sample. When the ratio is close to 100, the minor element still can be determined to around 1% or better. Therefore, in the hybrid system, KED determines the concentration of the major isotope and XRF determines the ratios of SNM.

The technique has proven in field tests to simultaneously assay mixtures of thorium, uranium, neptunium, plutonium and americium with ratios ranging from 100 to 0.01 without first separating them chemically. For single-element solutions in high concentrations, a bias of less than 0.2% and a precision of 0.2% have been achieved.

Integration of NDA Instruments and MC&A Systems

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Typically, when a container with special nuclear materials (SNM) goes through a nondestructive assay (NDA) to determine the types and amounts of its contents, it is tested by several different instruments. Each instrument prints its results out on a piece of paper, and a technician gathers these printouts and enters the data into a central computer for material control and accountability. In some cases, the data from one instrument must be entered into the controller for another instrument, because the latter needs that data to conduct its own assay.

This process presents several problems. One is the potential for a mistake by the technician entering the data. The second is the potential for someone deliberately falsifying information to cover up a theft or other diversion of SNM. Finally, steps of an assay might be delayed if an instrument does not get information it needs from another device in time.

Los Alamos National Laboratory is working on a method for NDA instruments to "talk" directly to each other and a central computer to eliminate the abovementioned problems. The first step is creating software that could understand the programs running most NDA devices. More software is necessary to take data from these devices and dump it into a common database. Both steps require considerable time to write the single, huge programs that would incorporate all the necessary computer code from each type of device. However, in the time since the project's beginning last year, major improvements have been made in software connection to different computer types. It is now possible for a single program to "borrow" programs from various computers, coordinating them with other borrowed programs so that they all work together.

Because of these advancements, Los Alamos is applying this kind of "component software" to safeguards activities, which promises both up front and long-term savings. At the start, time would be saved because the programming is much simpler. But long-term savings also are likely because when a component program is revised, the "glue" software does not have to have major (or any) changes made. It merely uses the updated component the same way it used the older version.

Los Alamos researchers had been planning on using a standard for computer interconnections known as Common Object Request Broker Architecture or COBRA. In recent months, Microsoft Corporation has introduced improvements in an architecture—the Distributed Component Object Model, or DCOM—that works well with widely used programming tools such as Visual BASIC. Though DCOM is not a standard adopted by other organizations and companies as yet, software exists that bridges COBRA and DCOM. Microsoft has proposed that a nonproprietary organization manage DCOM so it could become a standard.

In the meantime, DCOM has simplified the development of NDA component software. Los Alamos researchers have already completed the basic work on component software programming and are preparing to apply it to problems in a test NDA setup.

Automated Inventory Technology for SNM Storage Sites

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Figure 1. Oak Ridge National Laboratory's Continous Automated Vault Inventory System (CAVIS).

Traditional special nuclear materials (SNM) accountability programs, currently used within most of the DOE complex, require physical entry by highly trained personnel into the SNM storage vaults. This imposes additional security measures mandating extra security personnel during inventory. These requirements increase labor costs and put personnel at risk for increased radiation exposure. In some cases, individuals performing the inventory receive a radiation exposure equivalent to their annual dose maximum from just one inventory verification!

Three developments described here from Lockheed Martin Energy Systems are being installed at Oak Ridge National Laboratory's Y-12 plant where the nuclear materials for our nation's weapons were produced. Now, as part of national efforts to secure stockpiles of nuclear materials, we are looking at ways to decrease costs and still maintain control over the storage facilities, such as those at Y-12.

Continuous Automated Vault Inventory System (CAVIS) for Accountability of Special Nuclear Materials

As current inventory systems are becoming too expensive to operate, an automated method of inventory verification is desirable. The Continuous Automated Vault Inventory System (CAVIS) was designed and built as a low cost, highly reliable, and user-friendly system for remote inventory. It is capable of confirming the weight and radiation attribute in real time of each item stored in a SNM vault. CAVIS is currently being installed at Oak Ridge's Y-12 Plant. Information on the sensors in CAVIS, the software requirements for automated accountability, and sensor technologies for a plutonium system can also be obtained.

SmartShelf™ Technology: An Automated Container Identification System

SmartShelf™ is an inexpensive method to monitor the inventory of containers in an active storage area. The system continuously surveys items in its charge, thus reducing the time required to verify inventory from hours to minutes, and also eliminating the need for manual searches. As an added feature, SmartShelf™ can record the identity of the personnel moving containers and the time of day of the move. SmartShelf™ automates the who, what, when, and where associated with inventories.

SmartShelf™ uses standard modular telephone wire and jacks to connect up to 128 electronic identifiers (one identifier affixed to each container) to a controller. The controller includes firmware to detect additions or removals of containers, recognize alarm conditions, perform self-tests, and communicate with a host computer over an RS-485 serial communication line. Up to 32 controllers can be connected to the RS-485 line, allowing a single host to monitor with 4,096 containers.

Active Seal Systems

Traditional “passive” seal inspections rely on highly trained personnel who physically inspect Tamper-Indicating Devices (TIDs). These inspections are costly and sometimes have to be performed on a random-sampling basis when resources are limited. Physical inspections can also increase the risk of excess radiation exposure to personnel.

The optically based, active seal system immediately determines the time and location of any seal break. This system represents an “active” (meaning: continuously monitored) seal technology that monitors the status of thousands of reusable fiber-optic connectors (which individually serve as TIDs). The containers monitored by the system can be located nearby or several kilometers apart.

The optically based active seal system can be implemented in many different configurations. It can be connected to monitor containers in nearly any type of indoor or outdoor storage location. Containers may be connected individually or in groups. The seals (fiber-optic connectors) used with this system are reusable optical devices that do not have the limitations or vulnerabilities common to many electrical devices.

The total system consists of a control computer, an optical fiber multiplexer, and as many reusable fiber-optic connectors as needed. The fiber-optic connectors are affixed to containers in a manner where they can be easily disconnected when access is required. The system has a significantly lower per item cost than other active seal technologies and can be fully automated with minimal maintenance.

Figure 2. Oak Ridge National Laboratory’s SmartShelf.™

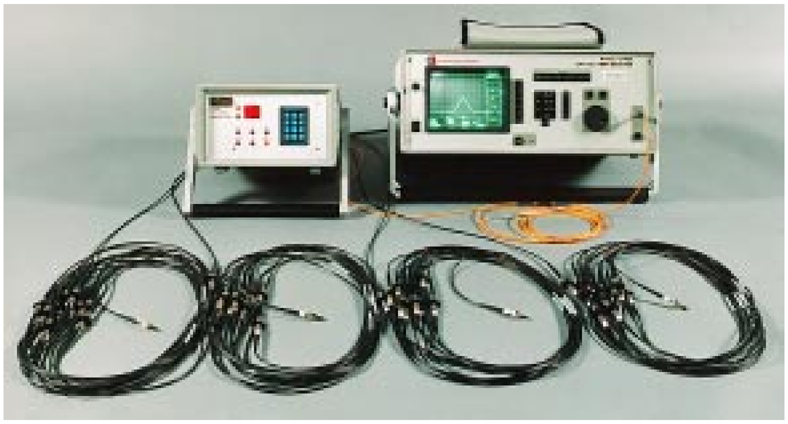

Figure 3. Oak Ridge National Laboratory’s optically based, active seal system.

Nuclear-Weapons Identification System

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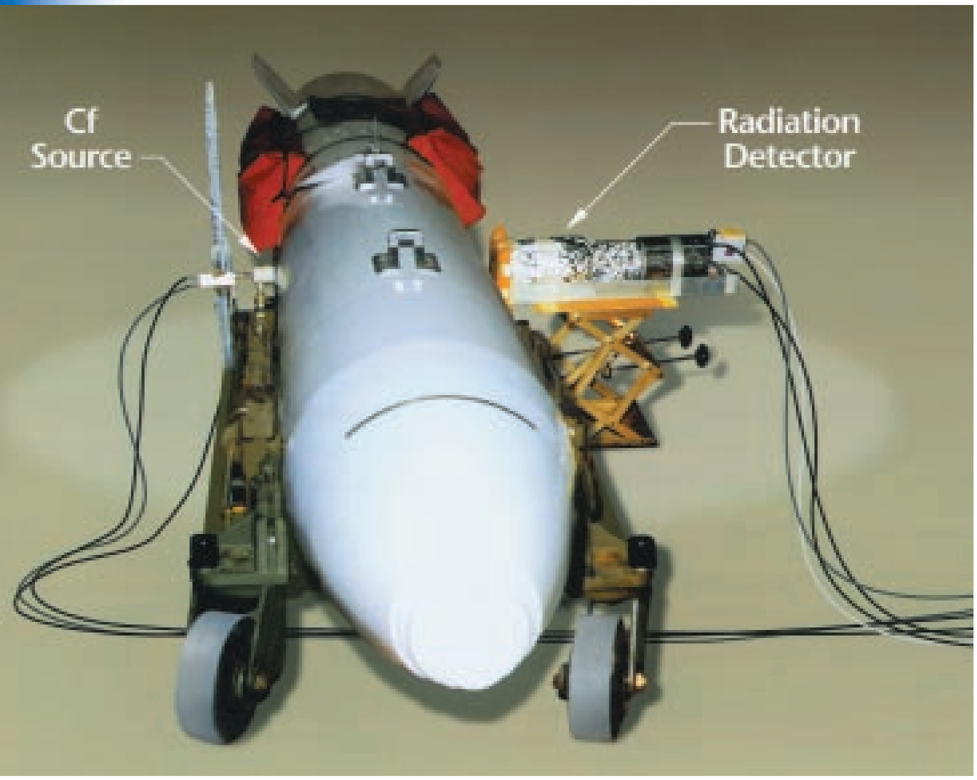

Figure 1. Demonstration of an axial scan of a nuclear weapon with the Nuclear Weapons Identification System (NWIS) at the Pantex Plant in Amarillo, Texas in 1988. The NWIS had been in development since 1984.

Oak Ridge National Laboratory's Nuclear-Weapons Identification System (NWIS), presently in use at the Y-12 Plant, uses active neutron interrogation with low-intensity ^{252}Cf spontaneous-fission sources in ionization chambers to provide a timed source of fission neutrons. Neutrons and gamma rays from the source enter the weapon or component, inducing fission internally in the fissile material. One or more detectors on the opposite side of the weapon (Fig. 1) detect the emitted radiation, which consists of three components: directly transmitted, scattered, and fission-induced. Data from the source ionization chamber and the detectors are processed using sophisticated time and frequency-analysis methods to yield a very robust signature consisting of 19 functions of frequency and time. Some of these signatures are not sensitive to background radiation from nearby materials or sources.

Until 1996, the extensive use of this method was limited by cumbersome hardware (bulky, low sampling rates, low processing rate, and long measurement times). A prototype NWIS processor improves performance by greater than a factor of 1,000 in size, sampling rate, processing rate, and measurement times over that available just 10 years ago (Fig. 2). For some systems, measurements can be completed in times as short as 10 seconds.

In late 1996, we initiated the development of a laptop version of the processor. In addition to hardware developments, we are also developing automated pattern recognition algorithms to confirm measurements and are packaging the detection systems for easy deployment.

Advantages of NWIS are (1) high sensitivity [small changes in configurations produce large changes in signatures]; (2) insensitivity of some signatures to background radiation, useful for storage configurations or for tracking secondaries through the first stage of dismantlement [the presence of the primary on the assembled system does not affect some signatures for the secondary]; (3) nonintrusiveness [does not reveal design information, which makes it useful for bilateral treaties or the International Atomic Energy Agency (IAEA)]; and (4) the difficulty in deceiving the system.

To date, we have measured 17 different weapons systems in a variety of configurations both in and out of containers (see Fig. 2). Those systems included pits and fully assembled systems ready for deployment at the Pantex Plant in Amarillo, Texas, and weapons components at the Oak Ridge's Y-12 Plant. NWIS can identify

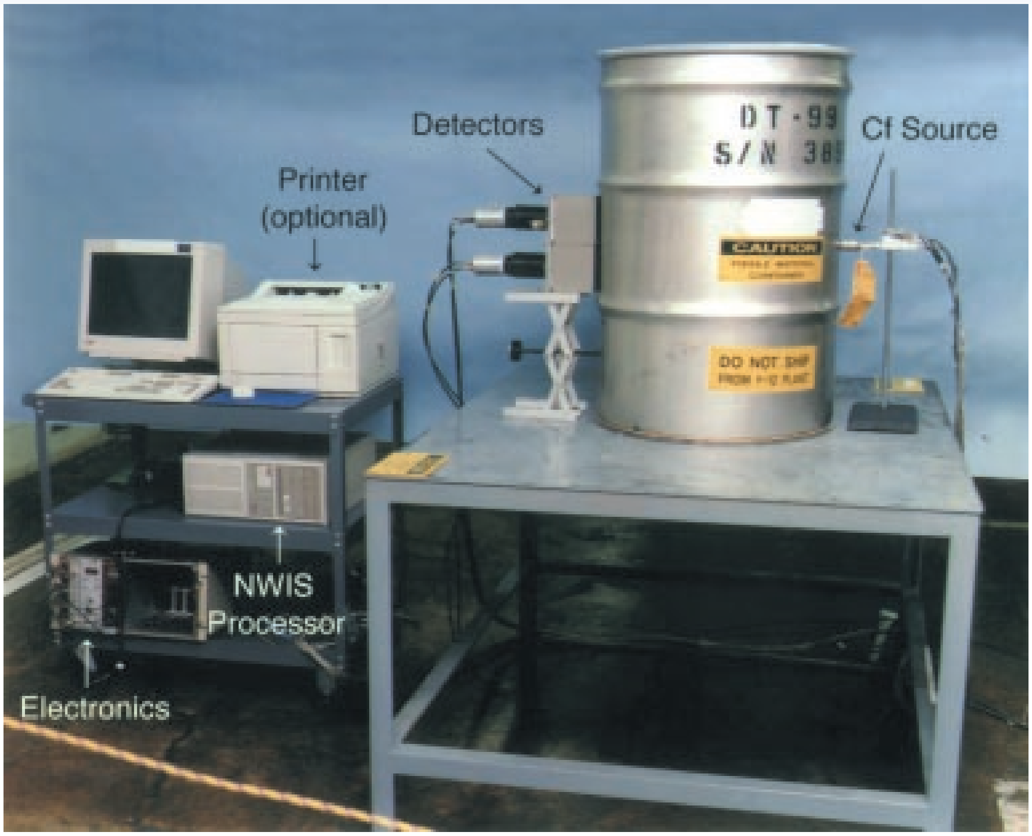

Figure 2. At Oak Ridge National Laboratory's Y-12 Plant, the NWIS is set up on a cart to look at a storage container. Current work is focused on consolidating the processor unit (seen on the middle shelf of the cart) into a laptop computer.

nuclear weapons and components; nuclear weapons or components can be distinguished from mockups where fissile material has been replaced by nonfissile. Secondaries can be tracked through the first stage of dismantlement. Omissions of small amounts (4%) of fissile material can be detected; changes in internal configurations can be determined. Trainer parts can be identified as was demonstrated by the verification of 512 containers with B-33 components at the Y-12 Plant (as many as 32 in one 8-hour shift). Nonfissile components can be identified.

Measurements show that NWIS can identify (by type) nuclear weapons or components and fissile material retrieved from dismantled weapons. It can track components and materials to their dismantlement, or confirm and verify declared storage, thus making it particularly useful for arms control and nonproliferation, domestic safeguards, and international agreements with countries or IAEA applications. This system is being used in the weapons dismantlement and storage program at Oak Ridge's Y-12 Plant. In addition to nuclear-weapons applications, NWIS signatures can be used for nuclear materials control and accountability, fissile mass assay and subcriticality of spent fuel, shipper-received confirmatory measurements, and nuclear-process monitoring. It has been used to verify, quantitatively by measurement, the nuclear criticality safety of highly enriched uranium (HEU) storage vaults at the Y-12 Plant (Fig. 3). For this vault loaded with uranium (93.2 weight % ^{235}U) metal annular castings (~19 kilograms uranium), the subcritical neutron multiplication factor measured was 0.797 ± 0.005.

Figure 3. Vault 16 at Oak Ridge's Y-12 Plant stores highly enriched uranium for subcriticality measurements.

Intelligent Video-Monitoring Technology for Nuclear Safeguards

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Figure 1. Each of 20 video cameras monitors a storage vault, recording individual video frames for use by the system software.

To help reduce the frequency of physical inventories for an increasing amount of nuclear materials in storage, Los Alamos National Laboratory developed the Inventory Verification System (IVS). The IVS provides real-time, computerized video analysis for nuclear materials in process or storage. By 1992, advances in computer technology had made real-time, computerized video analysis cost-effective. Before, the cost of the computing power required to analyze routine images made such a system prohibitively expensive.

Nuclear safeguards in the safekeeping of special nuclear materials verify the inventory and use of nuclear materials as reported by states that have signed the Nonproliferation Treaty. Nuclear safeguards are measures prescribed by domestic and international regulatory agencies implemented by the nuclear facility or the regulatory agency. Traditionally, these measures not only include destructive and nondestructive analysis of product materials and process byproducts, but also physical-protection measures for domestic safeguards (guards, fences, concrete barriers, and live video systems) and containment and surveillance for international safeguards (paper, metal, or fiber-optic seals and time-lapse video monitoring).

Video surveillance, in the past, has been limited to live video displays located in central control rooms, and is mainly used to view areas where other sensors have triggered an alarm. Advanced video technology have now made video a more valuable asset in protecting the world's inventory of nuclear materials.

Sponsored largely by the Department of Energy's Office of Safeguards and Security, Los Alamos has implemented new technologies such as IVS to enable DOE facilities to reduce the frequency of physical inventory of nuclear materials in storage while ensuring that these materials have not been tampered with or diverted.

The software driving the IVS installed in a vault acquires a reference image from each of up to 20 cameras connected to the computer. New images are compared with the reference image to determine if any changes or "events" occurred. Live images from 20 cameras can be analyzed every 10 or 15 seconds during a 24-hour surveillance of storage areas at a low cost relative to surveillance of the same areas by personnel.

The IVS also provides features that aid analysts in filtering normal facility operations from events with safeguards significance. "Regions of interest" (ROI), entered into the computer using a drawing mouse over the image "seen" by the camera, allows the computer to survey only the areas selected, allowing normal facility operations to continue in traffic areas while protecting materials or other objects within the ROI.

Since the development of systems like the IVS in the mid-90s, satellite- and Internet-based information technologies have added a mechanism to remotely monitor nuclear materials. Los Alamos is actively pursuing these technologies and their application to nuclear safeguards. New remote monitoring strategies now allow us to place video or radiation-sensing instruments at the facility being monitored, with access to the real-time data provided through facility-wide or world-wide networks like the Internet. Commercial advances in communications security make it possible to transmit this sensitive data between facilities, within a facility, or around the world without compromising the integrity of the nuclear safeguards information.

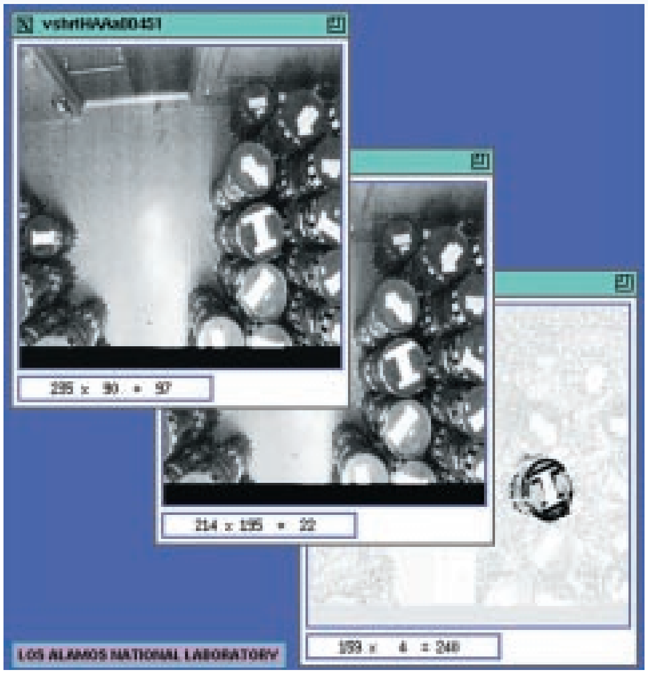

Figure 2. The software acquires reference images from the video cameras, comparing them to the continuous monitoring by video cameras. Acquisitions and comparisons are determined by the program.

Nondestructive Assay Systems for Automated Weapon Dismantlement

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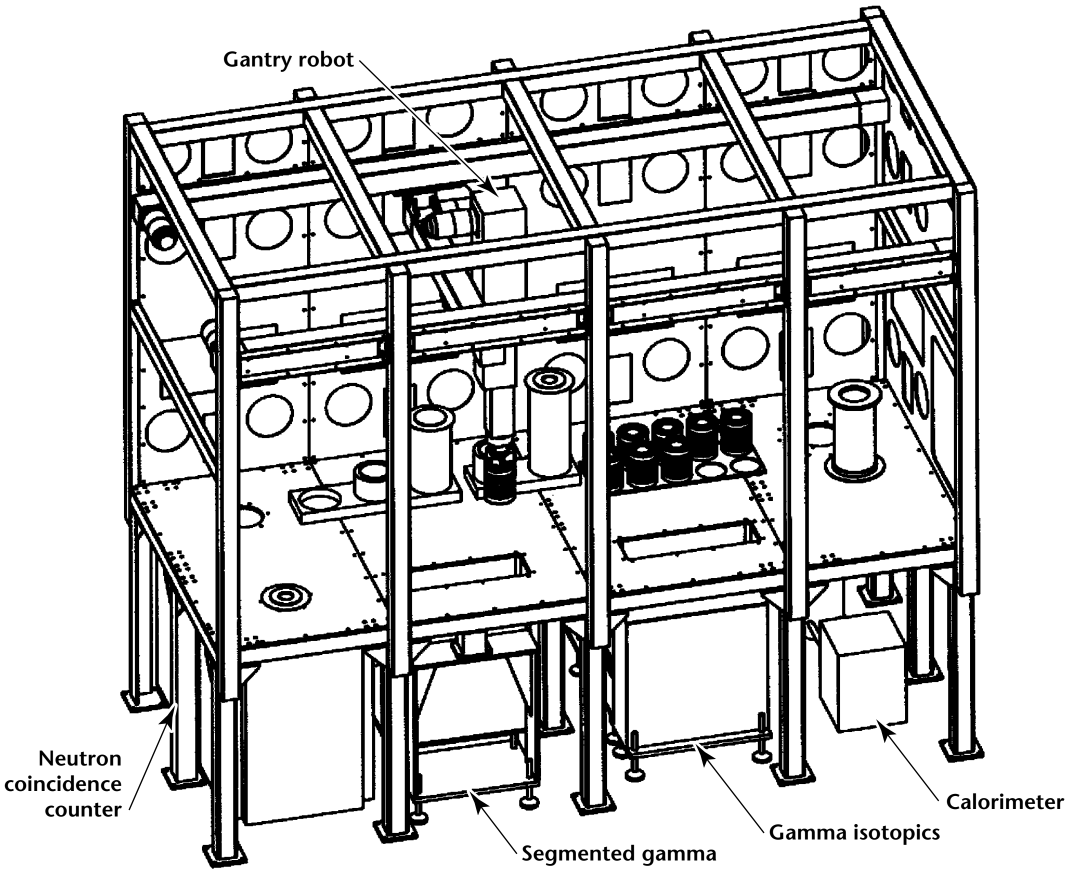

Figure 1. Sketch of the Advanced Recovery and Integrated Extraction System (ARIES) that will take the special nuclear materials from dismantled weapons and place them in storage containers.

The completed version of the Department of Energy's Advanced Recovery and Integrated Extraction System (ARIES) will take the special nuclear materials (SNM) from dismantled weapons and place them in containers for long-term storage. ARIES uses robotics to reduce materials-handling, reduce radiation exposure, increase productivity, and provide optimum safeguards for the materials. As part of its assignment to design the system, Los Alamos National Laboratory is developing subsystems that will automatically identify and measure the SNM.

ARIES starts with the placement of a nuclear core, or pit in the system. ARIES disassembles the pit, separates its component materials, converts its SNM into unclassified shapes, "cans" those shapes in containers designed to prevent radioactivity from escaping, decontaminates the outsides of the cans, and measures the amounts of SNM in each can to ensure material control and accountability.

To accomplish this last task, Los Alamos is integrating four devices for the nondestructive assay (NDA) of SNM, all designed and fabricated at Los Alamos. A calorimeter measures the heat produced during the radioactive decay of plutonium. Calorimetry is the single most accurate NDA measurement method for bulk materials. A plutonium isotopic analysis unit analyzes the gamma-ray emission and determines the isotopic composition (including americium) of plutonium or uranium. This measurement is used to convert other measurements to elemental masses. The third device is a segmented gamma-ray scanner that quantifies the gamma-ray emissions from plutonium or enriched uranium and determines the mass of ^{239}Pu or ^{235}U in low-density waste. Finally, a neutron multiplicity counter measures coincident neutrons from the spontaneous fission of plutonium or the induced fission of uranium. This versatile instrument may be used for both product and waste materials.

A robot moves the containers among the devices. It consists of a blend of commercially available components and Los Alamos-designed components. A host computer controls the whole process, interacts with individual instrument computers, commands the robot, and sends results to and receives information from the ARIES process control computer.

The prototype ARIES is scheduled to be installed at Los Alamos' Plutonium Facility this year to participate in tests of the full system. Meanwhile, design work on more advanced models continues.

Updated Applications Guide for Vehicle Portal Monitors

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Figure 1. A truck passing through a portal monitor is scanned automatically by detectors looking for radioactive emissions characteristic of special nuclear materials.

Nine years have elapsed since Los Alamos National Laboratory published its first applications guide to special nuclear materials (SNM) monitors for scanning vehicles at portals. Vehicle portal monitors are essentially radiation detection systems that look for the gamma rays and neutrons emitted by SNM as an effective means to quickly search the vehicle. Portal monitors range from small hand-held units to large automatic stations now in routine use at many protected-area boundaries. Their purpose is to provide the outermost layer of protection against the theft of SNM.

Since the original guide was published, automatic vehicle monitors have become more commonplace, and formal procedures for upkeep and evaluation have become available. New monitors have become available and new concepts for vehicle monitoring are being explored. Finally, changes in the disposition and storage of SNM require continued evaluation of the use of this technology. An updated report was needed not only to review the basics of SNM monitoring in vehicles but also to discuss what is new and catalog the commercially available vehicle portal monitors.

Los Alamos researchers first gathered information from Department of Energy (DOE) sites to determine what monitors were being used. Also, newly available monitors were evaluated. Besides reviewing in detail the technical basis for monitoring SNM in vehicles, the updated guide discusses new monitors and procedures that have evolved in recent years. Performance information for a variety of circumstances is given for a neutron-detection-based vehicle monitor and for several expanded versions of the conventional drive-through portal monitor. Operator training and maintenance and testing procedures are also discussed, and the pertinent ASTM Standard guides on application, evaluation, maintenance, and testing are briefly described. The final product provides the information needed by DOE and its contractors to specify, evaluate, calibrate, maintain, and use the technology. The result is reduced security costs and more effective vehicle monitoring. This updated guide will be available from Los Alamos in 1997.

Los Alamos Nuclear Material Accounting System—LANMAS

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LANMAS is an automated, nuclear-material accounting system using client/server architecture and a relational database. LANMAS tracks all activity affecting the status of nuclear material at a site. The fundamental design philosophy behind LANMAS is providing an easily expandable system compatible with site-specific enhancements and functions.

The core database resides on the server; the user interface is local to the clients' computers who can access the server via a network connection. All source code is provided so that an individual site may develop software to meet its interface specifications. Such code addresses site-specific requirements and the local work culture, including user interface forms (or screens) and reports. Twelve person-years went into the development of the software that was rigorously documented according to IEEE software engineering standards. It is also undergoing formal verification and validation testing by an independent software-testing firm. The beta version of LANMAS has been in the field for over six months and is being implemented at seven U.S. nuclear-material facilities.

The core database was designed to capture as many attributes of nuclear material as required for complete accountability. Each material in the inventory can be characterized by any number of elements, which can be characterized by any number of isotopes. By fully characterizing the material, the information in the database addresses multiple customer needs.

User sites may validate input data before interfacing with the core application and can develop additional screens and reports to comply with their operational requirements and work culture. LANMAS includes sample forms and reports. The user interface software is written in Microsoft Visual Basic, to rapidly develop user screens.

The core database includes the following functions:

- Material movement and transfers
- How materials are contained
- Accounting-period closing
- Tamper-seal tracking
- Instrument tracking
- Physical inventory
- Complete history of item transactions
- Support for standard and *ad hoc* queries
- Reports for national accountability system (NMMSS)
- System maintenance and administration
- User access control

In the future, data will be barcoded, statistical analysis tools will be added, data from nondrestructive assay instruments will integrated, and anomalies and errors will be detected automatically.

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